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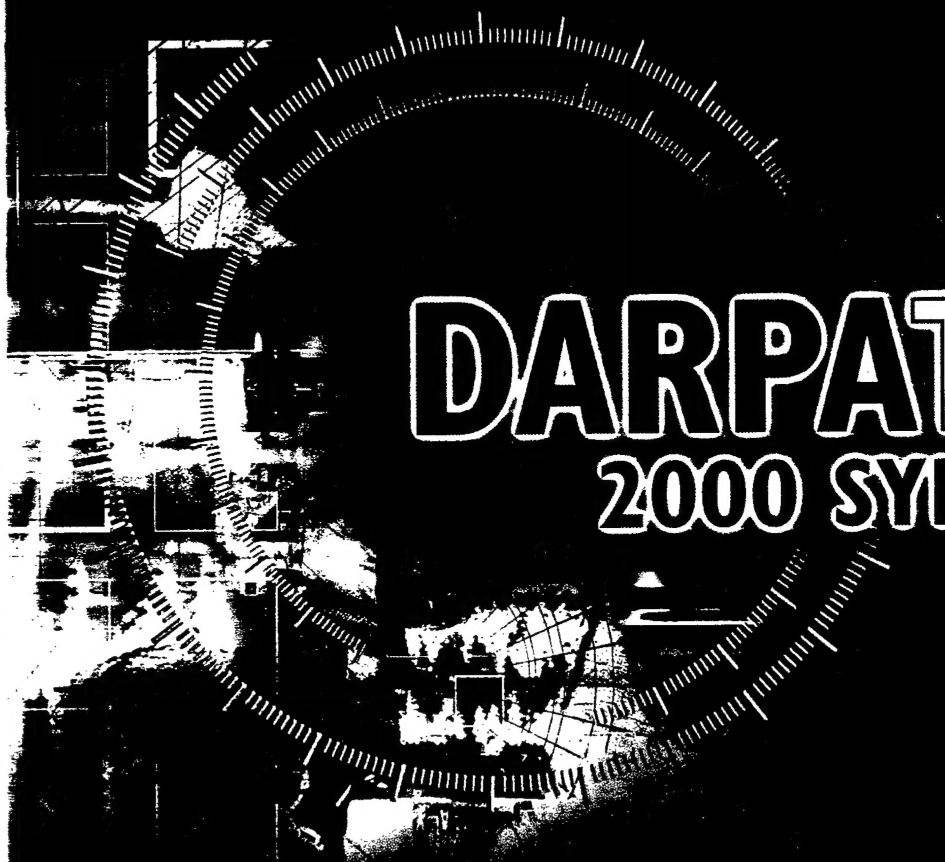

DARPATECH 2000 SYMPOSIUM

DARPA

TRANSFORMATION THROUGH TECHNOLOGY INNOVATION

Wyndham Anatole Hotel Dallas, Texas
SEPTEMBER 6-8, 2000

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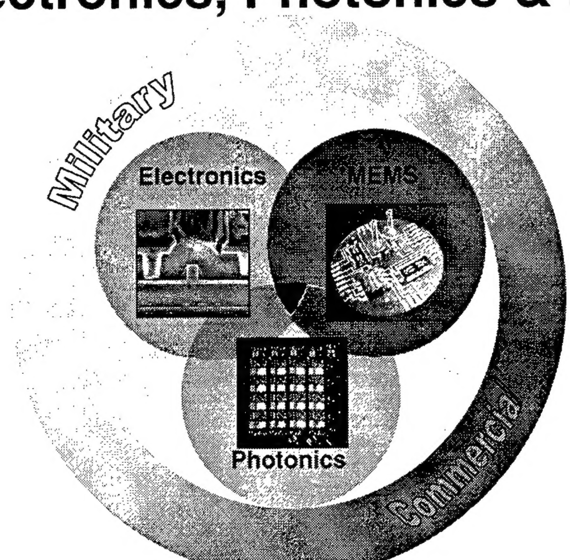
Microsystems Technology Office (MTO)

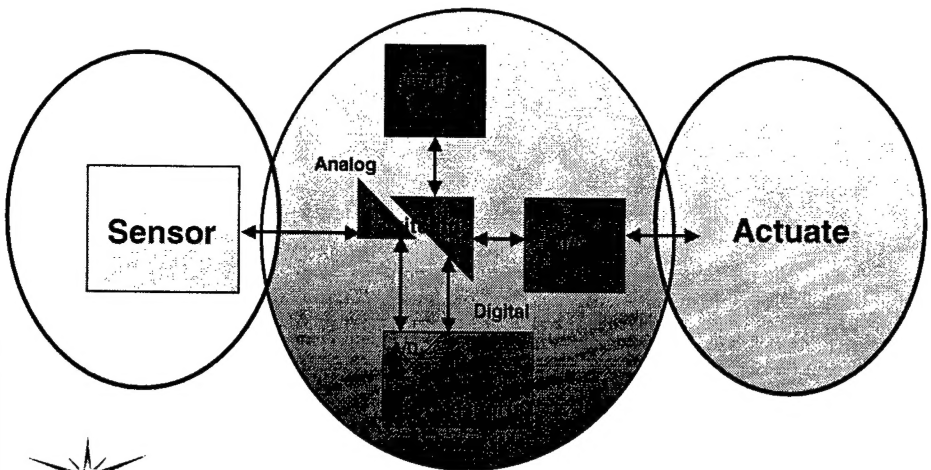
DARPATech 2000

Dr. Robert Leheny, Director

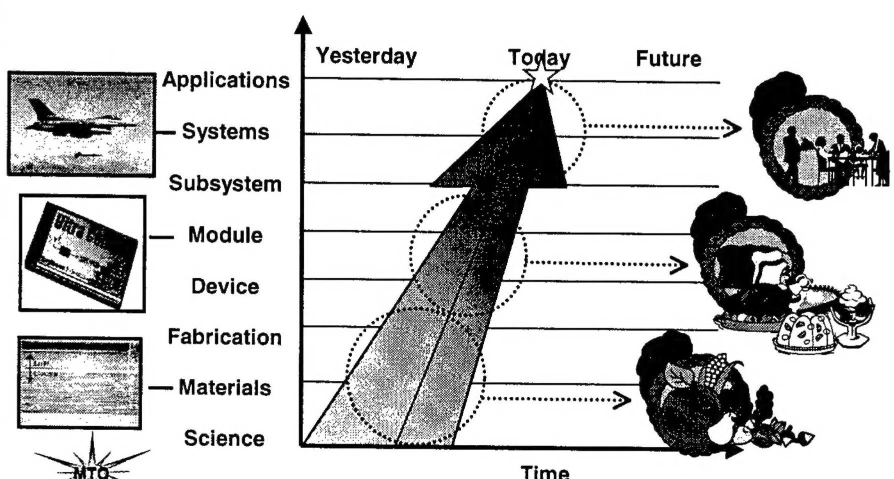
Driving a New Chip Scale Revolution in Electronics, Photonics & MEMS



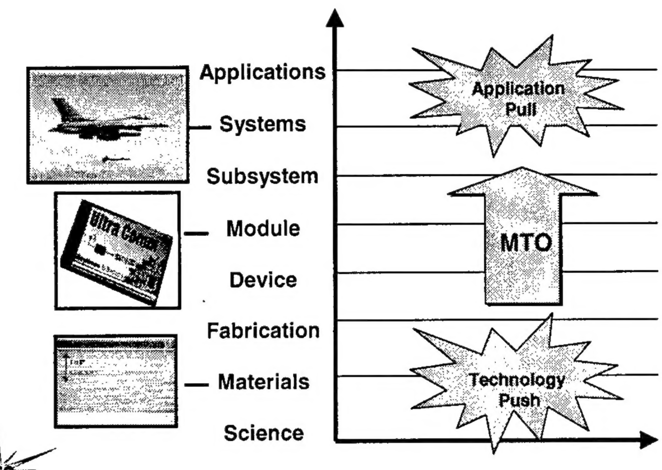
Platform Scale Information Systems



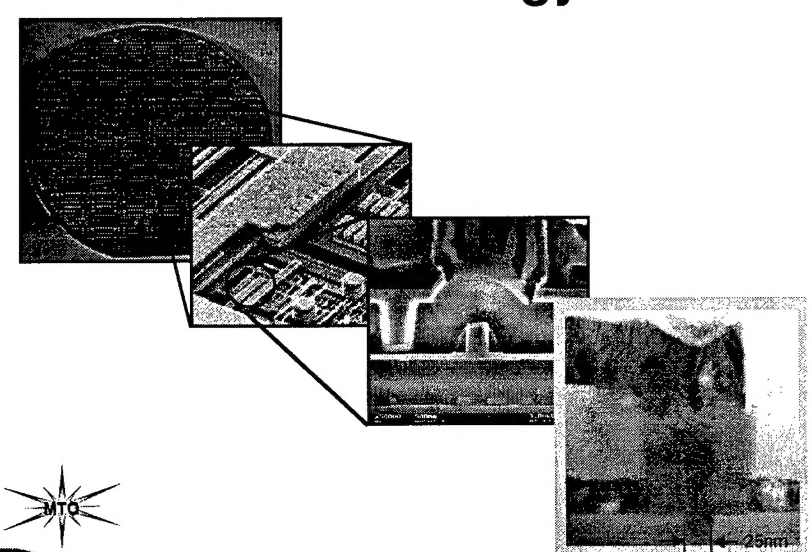
Flow of Technology Innovation



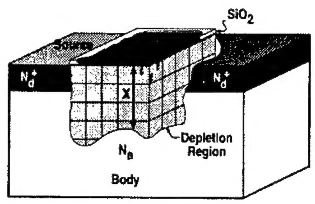
Flow of Technology Innovation



Advanced Micro Electronics Technology



Beyond Silicon-CMOS: The Limits of Scaling



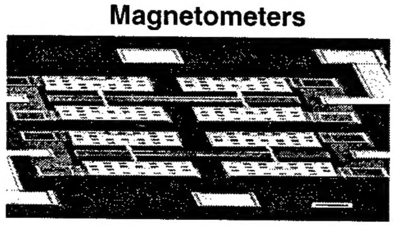
Random Dopants

Physical Challenges to Continued Scaling:

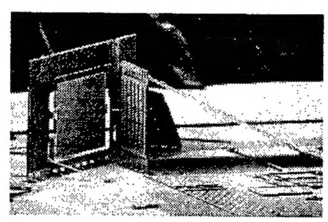
- Contact Resistance
- Statistical Variation in Channel
- Atomic Oxide Thickness
- Approaching Molecular Scale Devices

Micro Electro Mechanical Systems

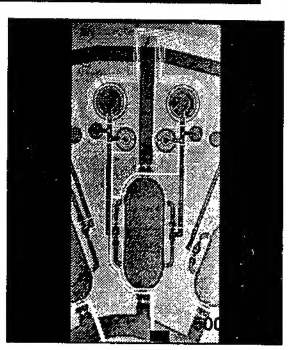
Magnetometers

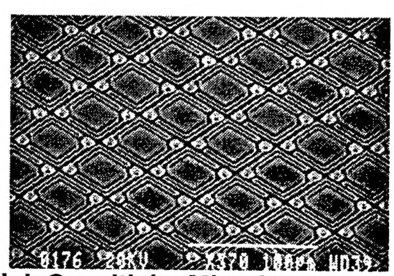


Laser Deflection



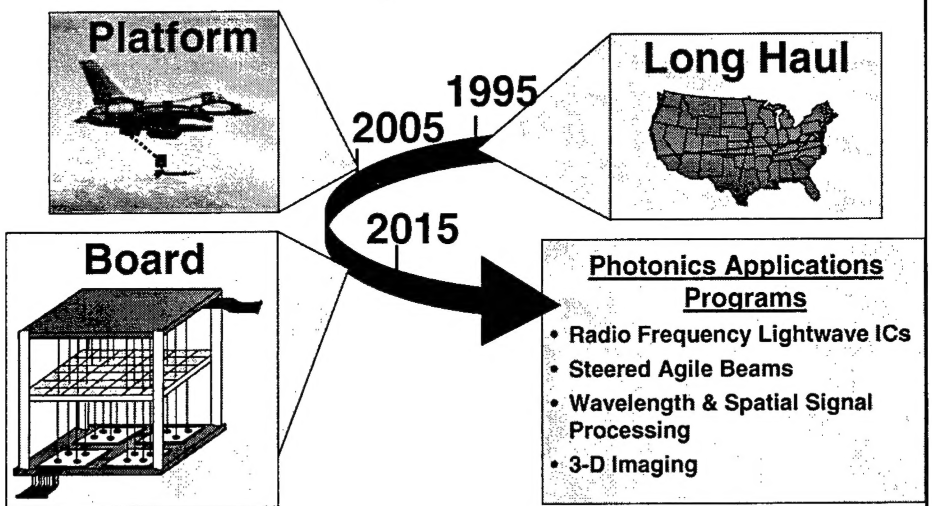
MicroFluidic Pump





High Sensitivity Microbolometers

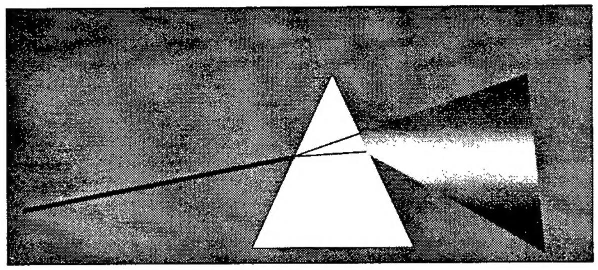
Photonics in Military Information Systems



Outline of MTO Presentations

Office Overview	R. Leheny
Photonics Overview	E. Towe
From Microelectronics to Nanoelectronics	C. Marrian
MEMS & Micro Power Generation	W. Tang
Bio-Fluidic Chips (Bio-Flips)	A. Lee
Design of Integrated Mixed Technology Microsystems	A. Krishnan
Gallium Nitride and Related Wide Bandgap Materials and Devices	E. Martinez

MTO



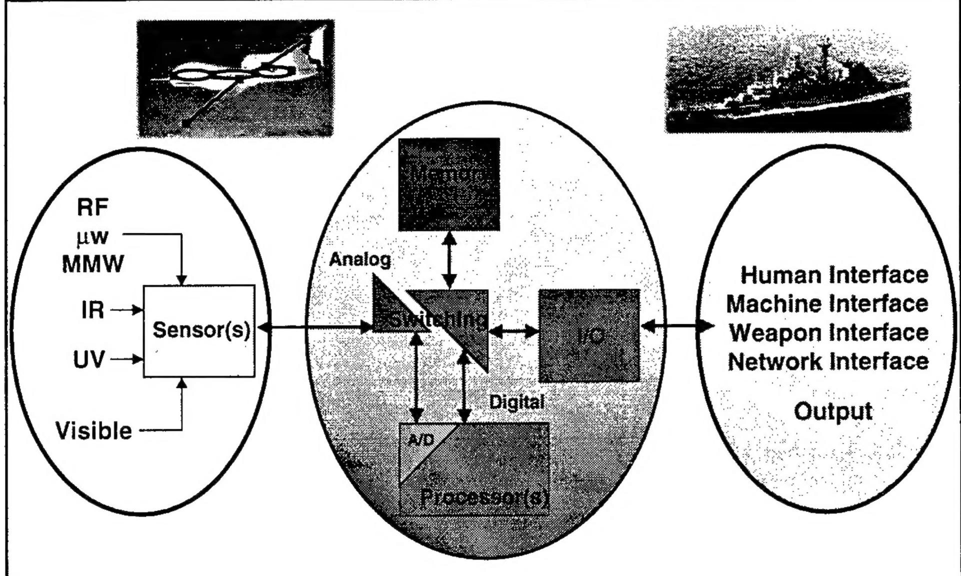
Photonics Overview

Elias Towe

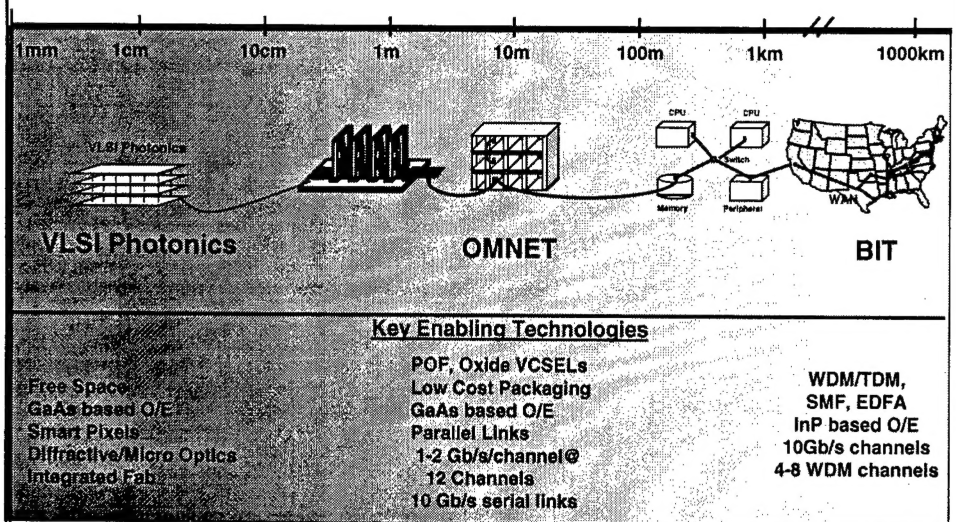
DARPA/MTO

DARPATech 2000

Military Platform Information System Functions



Recent DARPA Thrusts
Digital Data Communications



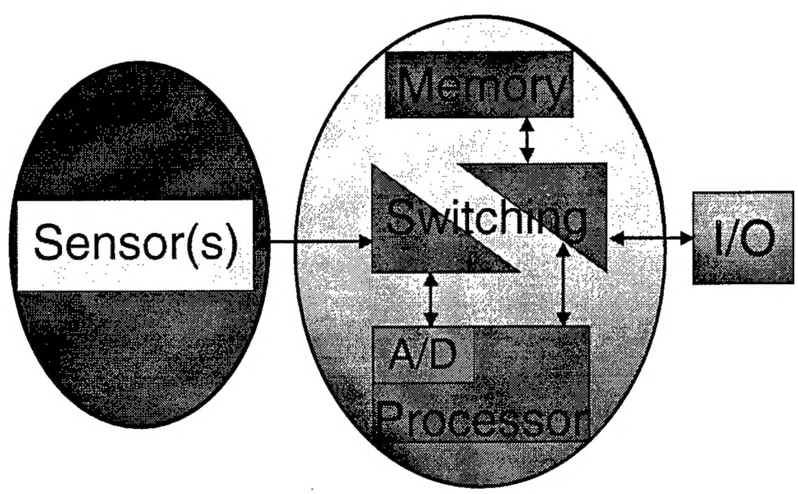
MTO - Photonics Programs

- Sensing
  - IR Sensitive Materials; GaN Sensors; Photonic WASSP
- Communication
  - RF Photonics; Steered Agile Beams (STAB)
- Processing
  - VLSI Photonics; Photonic A/D Converter

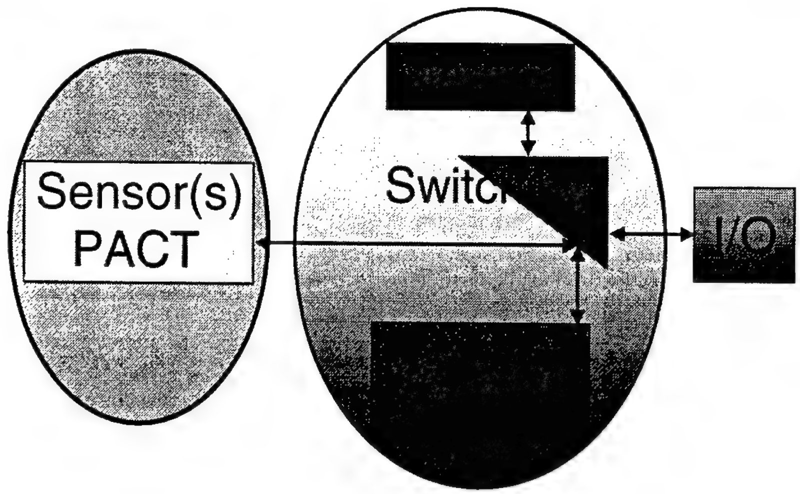
MTO - Photonics Program Managers

- Sensing
  - R. Balcerak, E. Martinez, E. Towe
- Communication
  - D. Honey
- Processing
  - D. Honey, J. Murphy, E. Towe

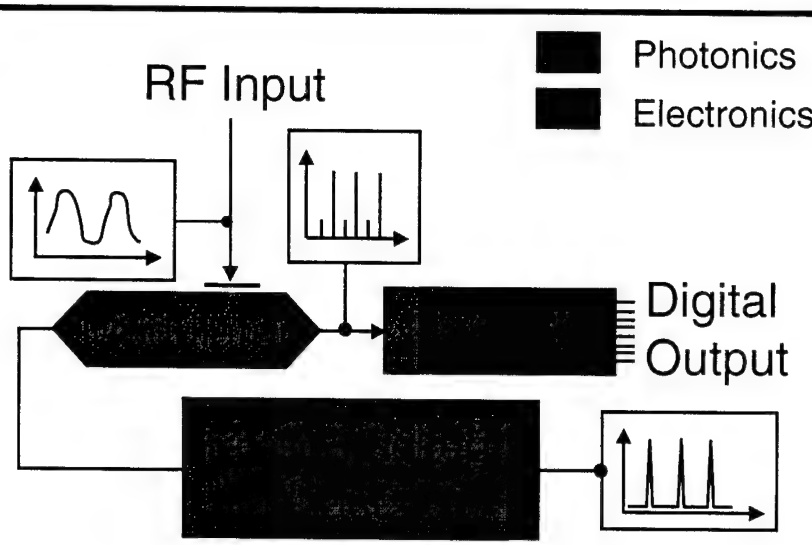
General Architecture



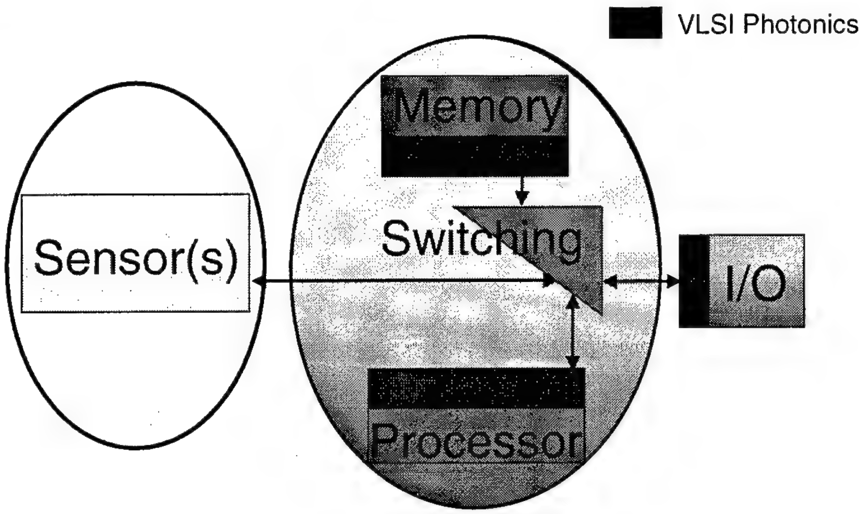
Photonic A/D Converter



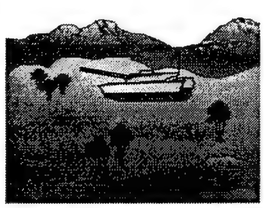
Photonic A/D Converter



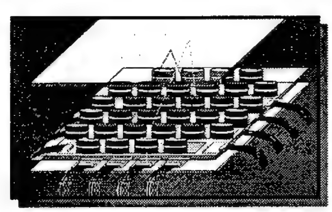
VLSI Photonics



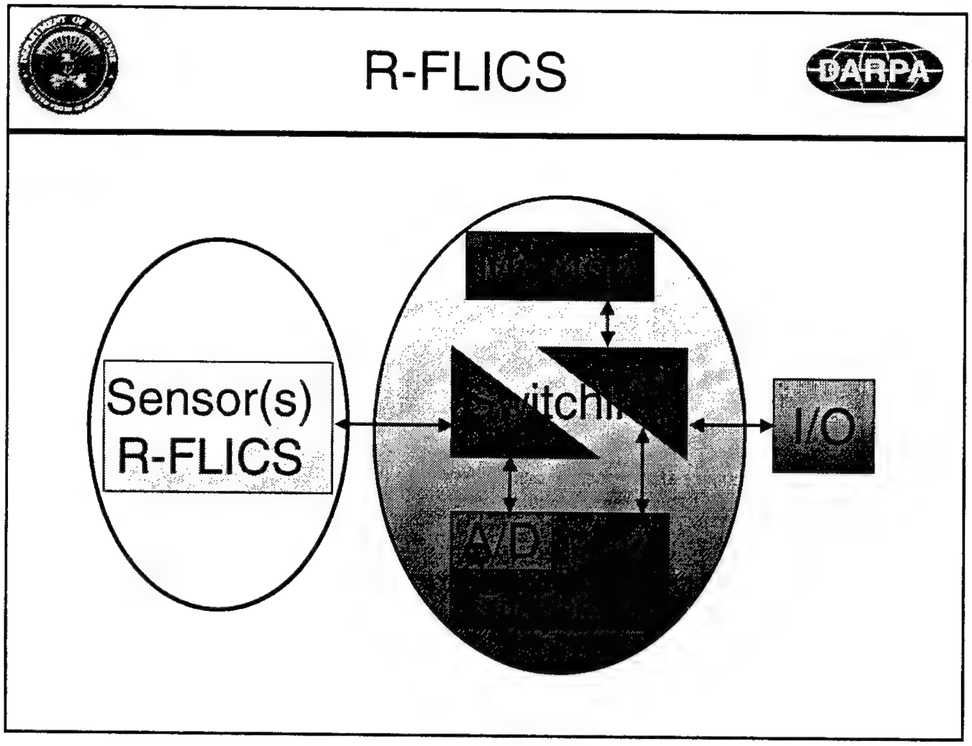
VLSI Photonics

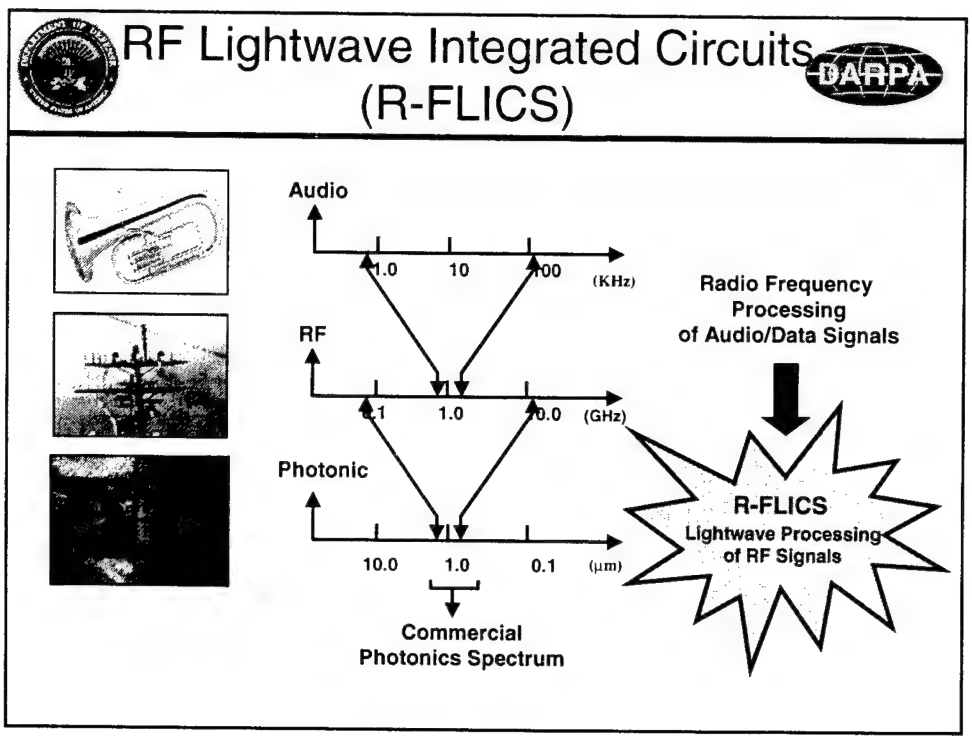


TBytes of Information

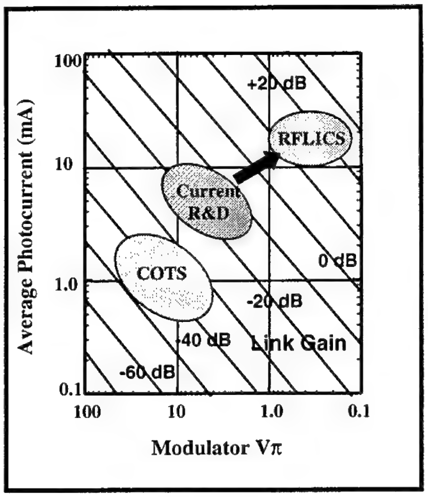


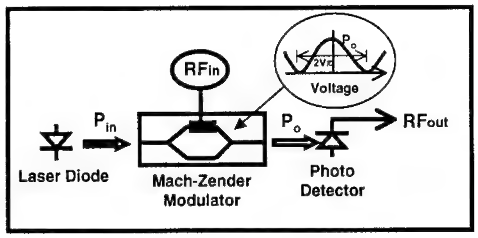
Chip-to-Chip Optical Interconnect


R-FLICS
Sensor(s)
R-FLICS
I/O


RF Lightwave Integrated Circuits
(R-FLICS)
Audio
1.0
10
100
(KHz)
RF
0.1
1.0
10.0
(GHz)
Photonic
10.0
1.0
0.1
(μm)
Commercial
Photonics Spectrum
Radio Frequency
Processing
of Audio/Data Signals
R-FLICS
Lightwave Processing
of RF Signals

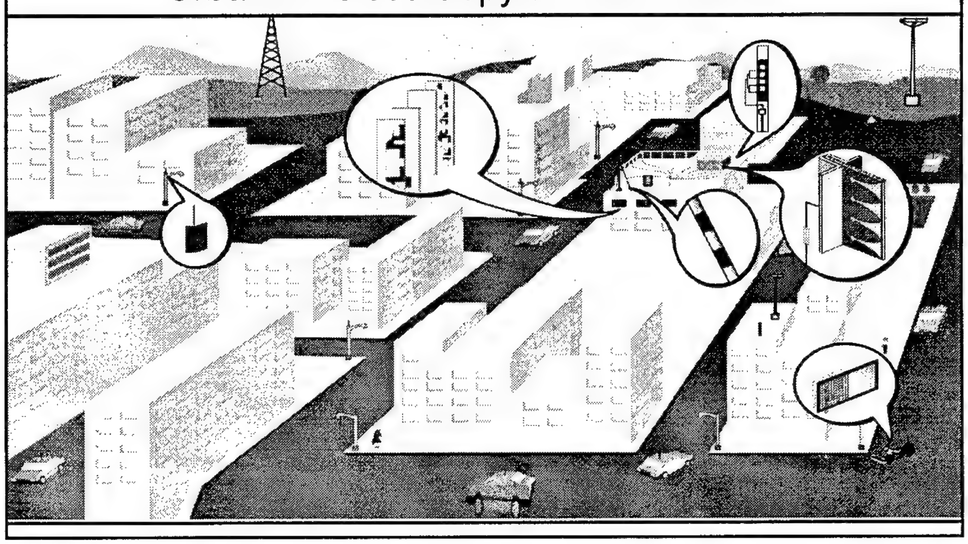
RF - Photonic Link Performance



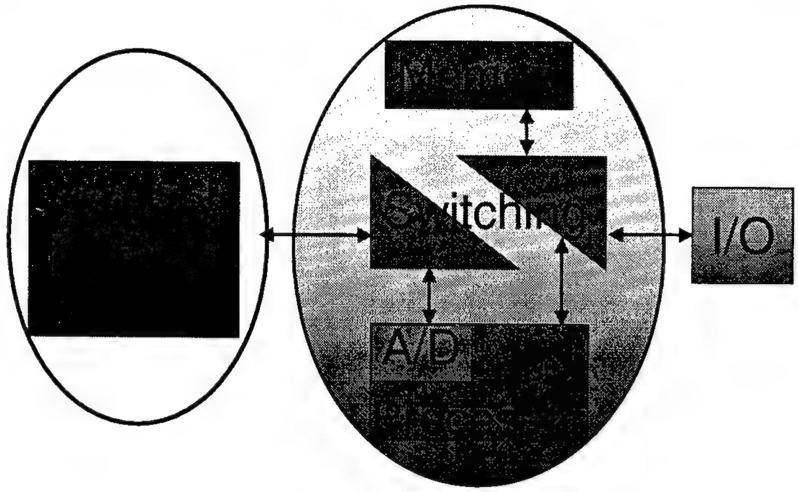


R-FLICS Application Example

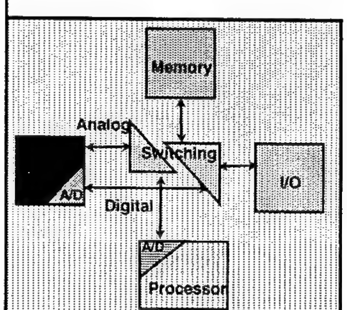
Urban Wireless Copy and Geolocation



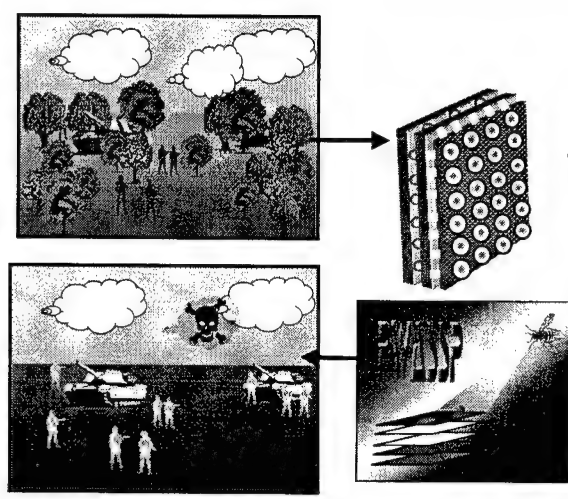
MTO Sensor Programs



Photonic WASSP



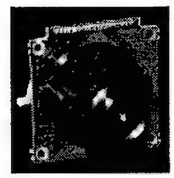
Photonic WASSP

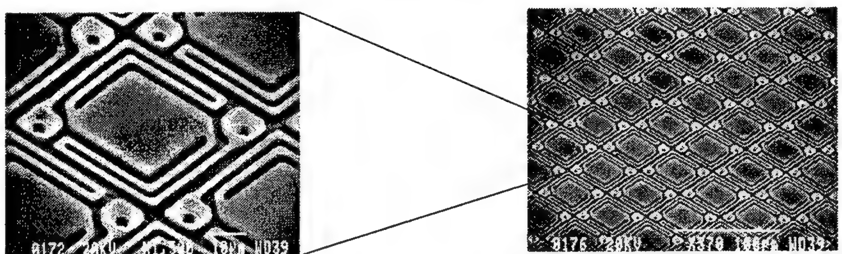


Advanced Uncooled IR Sensors

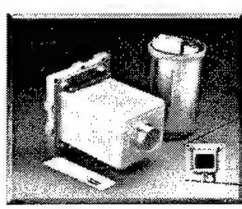

Missile Seeker

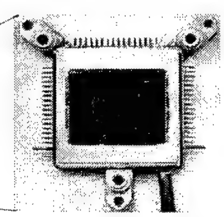

Target Acq.


Micro Sensor


High Sensitivity Microbolometers

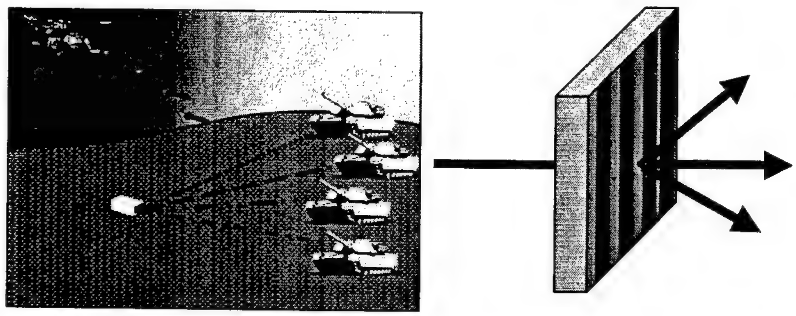
Why Uncooled IR Sensors?


Cryogenic Sensor


Uncooled Flat Pack

- 20 x Power reduction
- 10 to 100 x reduction in size
- 10 x Cost reduction

Steered Agile Beams



Multiple Target Engagements

Summary

- Use of photonics in analog and digital military/commercial systems in sensing, communications, and some limited signal processing
- Photonics can offer unique performance characteristics that purely electronic systems cannot
- Today, it is evident that significant benefits exist if we compute with electrons but communicate with photons

From Microelectronics to Nanoelectronics

Christie Marrian
DARPA MTO
DARPATech 2000

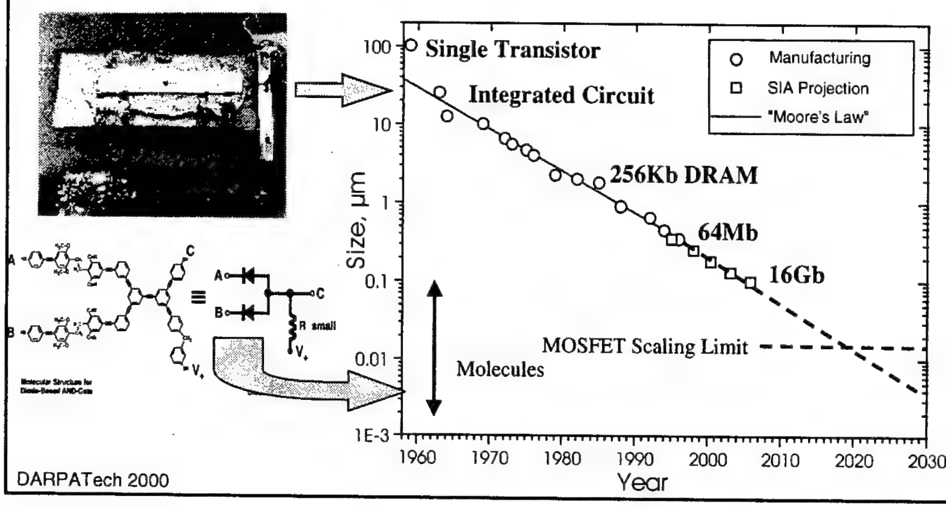
cmarrian@darpa.mil

Overview

- Microelectronics is becoming Nanoelectronics
  - 18 nm transistors
- Challenges and Opportunities
  - Terabit circuits
  - Patterning
  - The molecular electronics approach
  - Designer materials
  - Integrated nanostructures

Microsystems Length Scales

- Si scaling limits: one switch per ~100,000,000 atoms
- Molecules are multifunctional: one operation in ~100 atoms
  - Logic Element, Memory, Sensor



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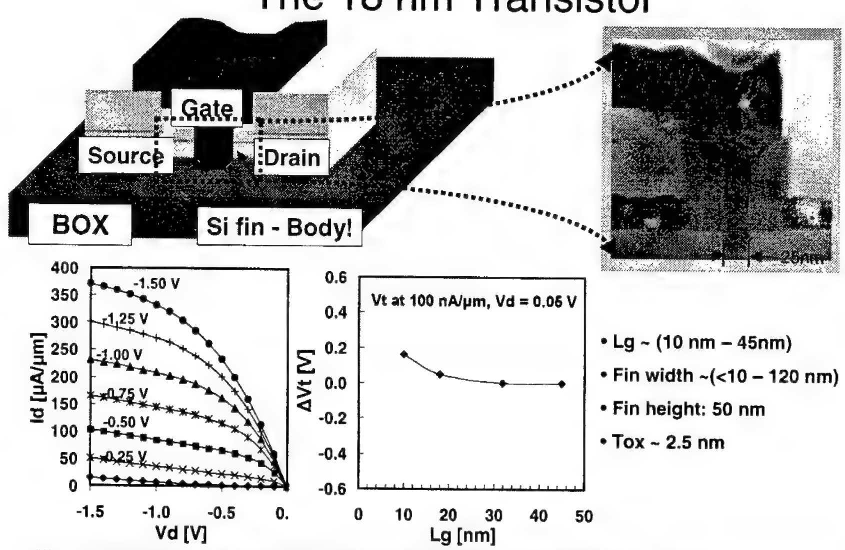
The 18 nm Transistor



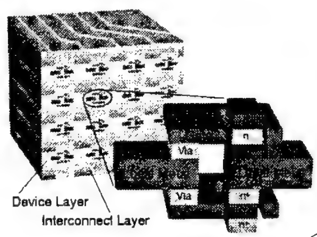
- Lg ~ (10 nm – 45nm)
- Fin width ~(<10 – 120 nm)
- Fin height: 50 nm
- Tox ~ 2.5 nm

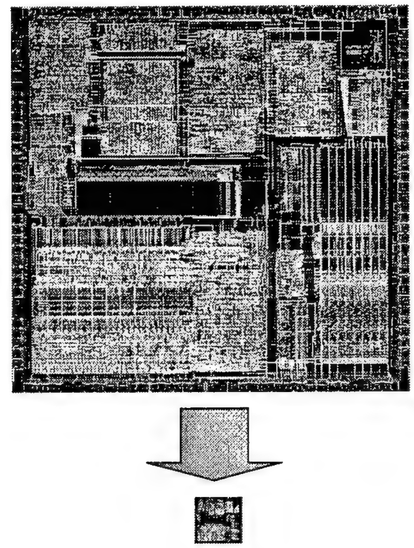
Deep Scaling - World's Shortest Gate Length FET (18 nm) With Useful Electrical Characteristics (IEDM 1999)

DARPATech 2000

The Challenge of the 20 nm Transistor Circuit

- $>10^{10}$ transistors per chip
  - Patterning
  - System design





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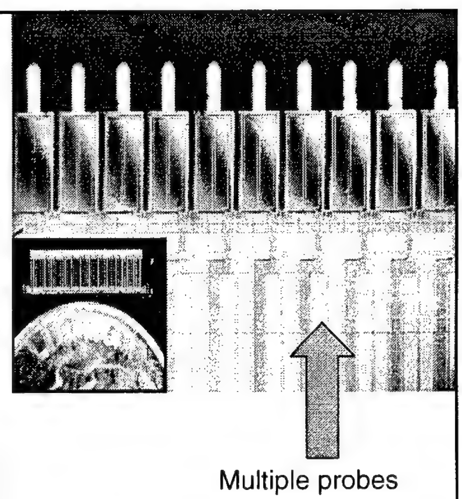
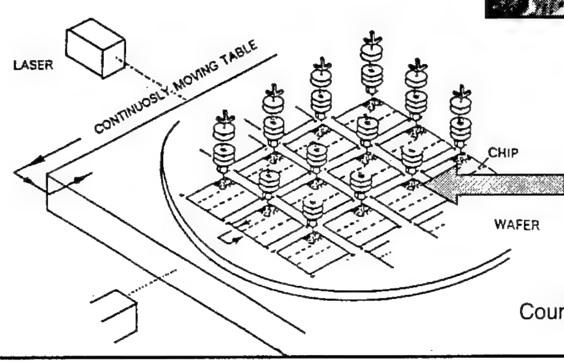
Maskless Patterning

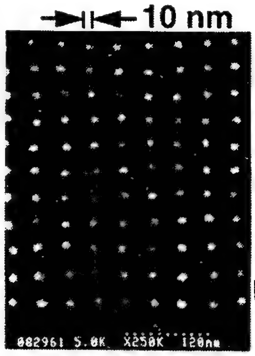
- Low volume (~1000 wafers per mask) dominated by mask cost
- Eliminate mask!



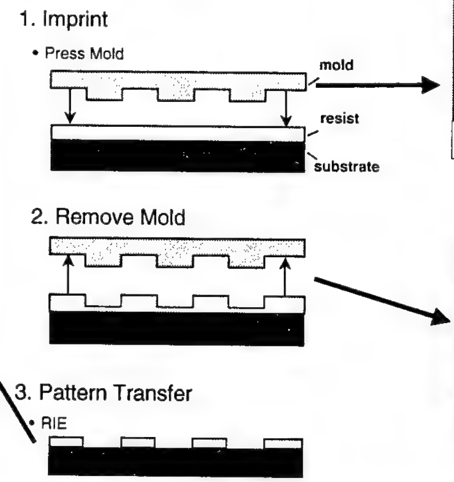


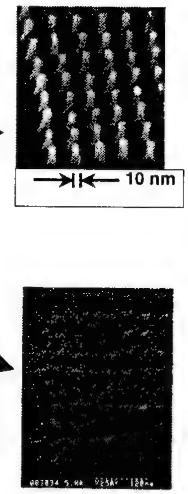
Courtesy of Stanford University and ETEC

Nanoimprinting (Chou, Princeton Univ.)



10 nm Metal Dots



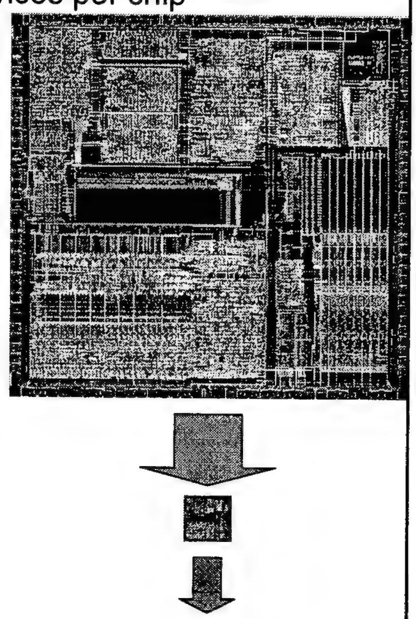


- Phenomenal resolution over large area
  - <10nm over several cm^2
- Wide range of 'printing actions'
  - Patterns of self-assembling 'ink'

Moletronics (Molecular Electronics)

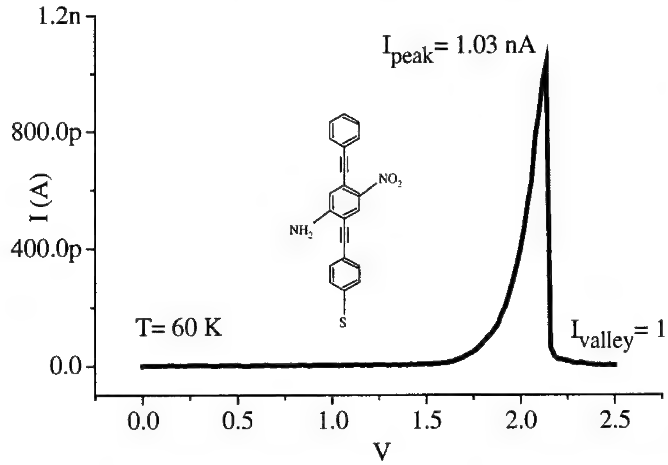
The roadmap to 10^{11} devices per chip

- Molecular based switches
- Assembly rather than fabrication
  - Defect tolerance
- Scalability



DSO ITO Moletronics

Electrical Properties of Molecular Diodes



PVR = 1030:1
J = 53 A/cm^2
NDR = -380 $\mu\Omega$-cm^2

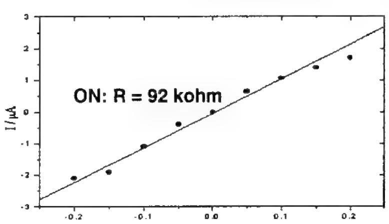
- <30nm diameter active device
  >10^{10} bits/cm^2
- Room temperature
- Reversible

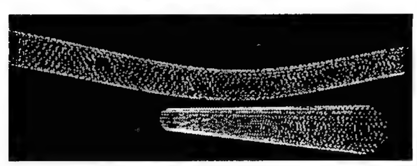
Yale University, Rice University
DARPATech 2000

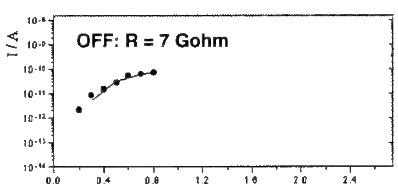
Control of electronic properties by chemistry

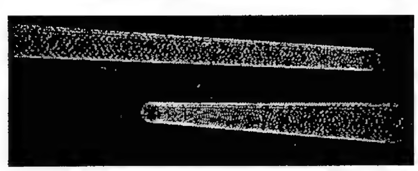
Carbon Nanotubes: <10 nm^2 memory bit

- Large on-to-off ratios (10^5:1)
- Low power: CMOS ~ 1 nW/device,
  Cross bar < 1 pW/device









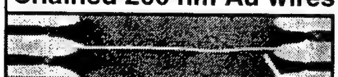
Room temperature reversible memory

Harvard University, Stanford University

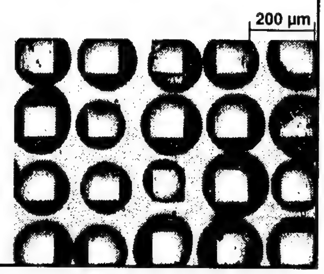
Hierarchical Assembly: An alternative to slicing and dicing

- Let thermodynamics do the hard work
  - Molecules and nanowires into nano-arrays
    - Carbon nanotubes
    - Molecular self-assembly
  - Nano-arrays into micro-modules
    - Field driven alignment
  - Input and output
    - Fluidic assembly

Chained 200 nm Au wires



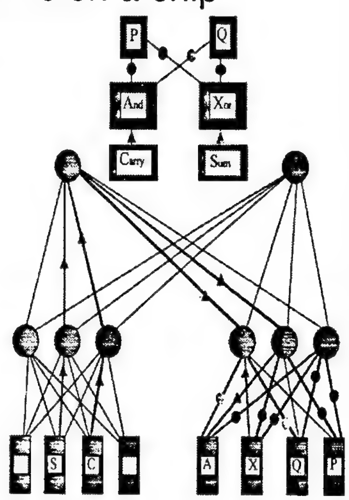
E-field Assembly, Penn State



Fluidic assembly of arrays of spheres, HRL

Scalability

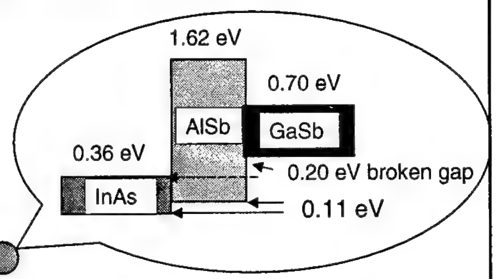
- Scaled CMOS ⇒ Gigascale systems on a chip
- Moletronics has the potential of tera (not terror) scale integration
  - 10^{12} devices
- Need systems architectures to be scalable to these levels
  - Defect tolerance
  - Programmability
  - Access times
- Hard challenges but enormous **pay-off**

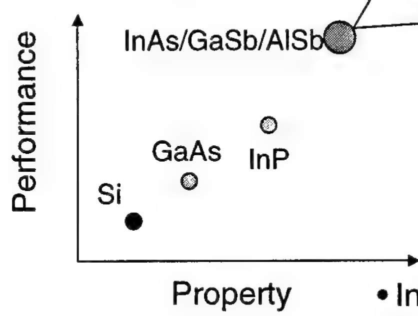


UCLA/HP: Fat Tree Architecture

Nanoelectronics: New Materials

- Increased speed
- Decreased power
- Lower noise figure



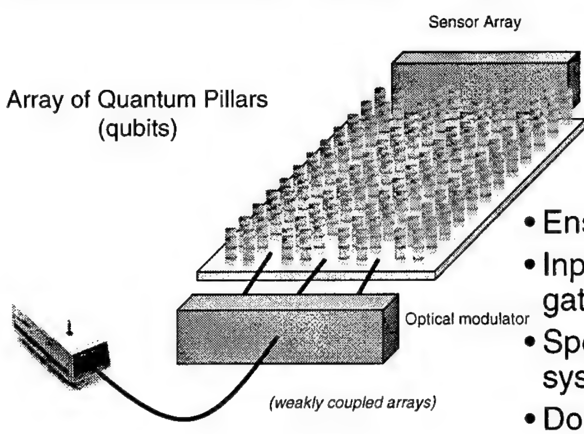


Lower consumed power
>100GHz operation

- Increasing mobility
- Decreasing bandgap
- Increasing lattice constant
- Decreasing effective mass

Nanoelectronics: New Challenges

Scalable Quantum Computing



- Ensemble of devices/qubits
- Input signal acts as a logic gate
- Spectroscopy to read system output
- Does not require connectivity or coupling between adjacent devices

The Future

- Incredible opportunities and challenges exist
  - Multi-functional electronics systems combining the best attributes of inorganic and organic materials
- We aren't done yet!

MEMS &
Micro Power Generation (MPG)

DARPA Tech 2000

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Program Manager
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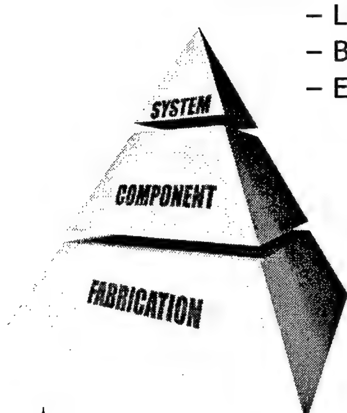
http://www.darpa.mil/MTO/MEMS

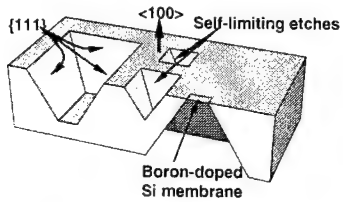
Micro Electro Mechanical Systems – A Core Technology

MEMS is a core technology that:

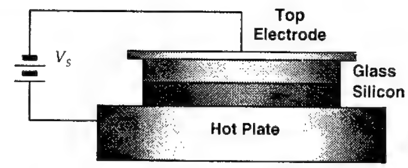
- Leverages IC fabrication technology
- Builds ultra-miniaturized components
- Enables radical new system applications



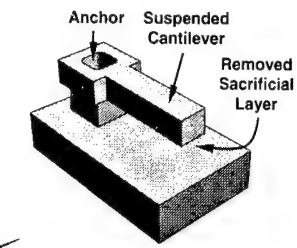
MEMS Fabrication Technologies



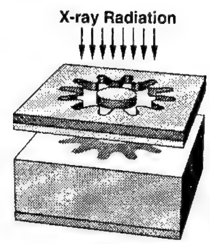
Anisotropic bulk etching



200°C $< T <$ 500°C
200 V $< V_S <$ 1000 V
Anodic wafer bonding



Surface micromachining



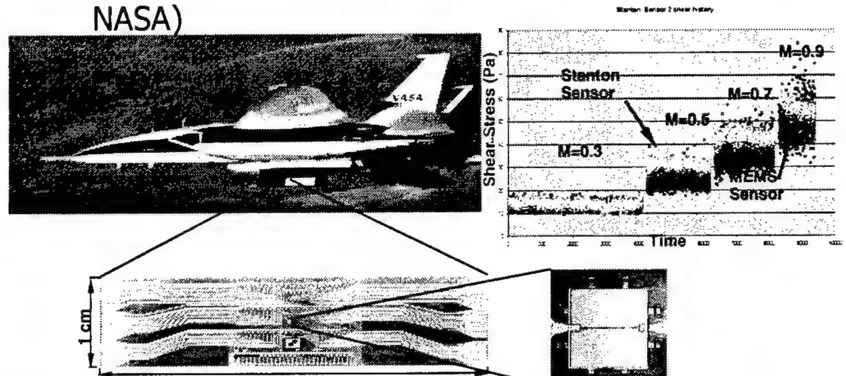
LIGA

Advantages of MEMS

- **IC Technology** → *Integrated Multiple Functions*
- **Precision** → *Improved Performance*
- **Batch Fabrication** → *Reduced Manufacturing Cost & Time*
- **Miniaturization** →
  - *Portability*
  - *Ruggedness*
  - *Low Power Consumption*
  - *Easily & Massively Deployed*
  - *Easily Maintained & Replaced*
  - *Little Harm to Environment*

Shear Stress Sensor for Jet Fighter (Caltech)

➤ Demonstrated 10X more bandwidth over state-of-the-art sensors in F-15 flight test (co-funded by NASA)

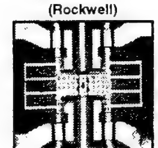


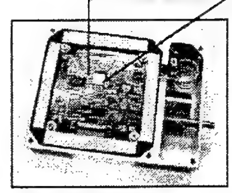
MEMS shear-stress sensor (200 μm X 200 μm)

Pico Satellites (Aerospace Corp., et al.)

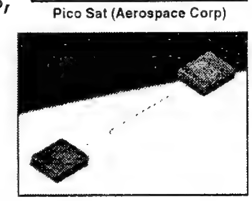
- Pico satellites
  - ➤ Weight & Size: 250 gm, 2.5 x 7.5 x 10 cm
  - ➤ A platform for testing MEMS devices and microsystems for space applications
- Potentials
  - ➤ Cooperative constellations
  - ➤ Sparse aperture antennas
  - ➤ Inspect and service missions
  - ➤ Launch-on-demand, robust communications, and surveillance space systems
- First demonstration:
  - ➤ Launched 26 Jan 2000
  - ➤ RF communication established 7 Feb 2000
  - ➤ Operated MEMS RF switches in space

MEMS RF Switch (Rockwell)



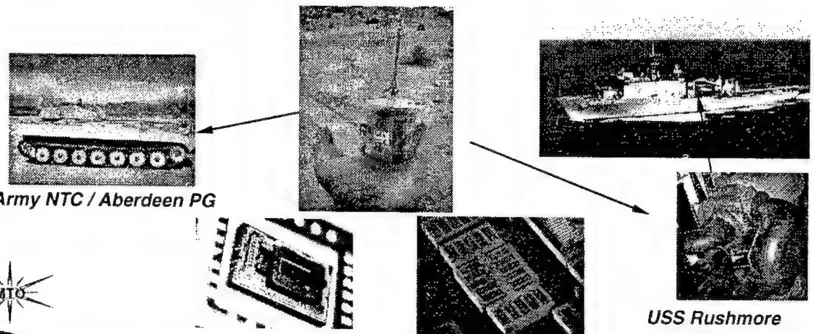


Pico Sat (Aerospace Corp)



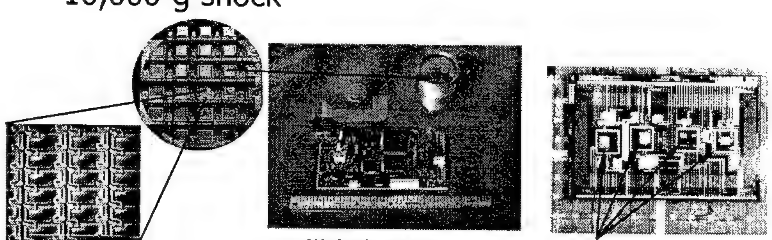
Wireless Integrated Network Sensors (UCLA, et al.)

- Demonstrated embedded processor, radio links, multihop network, and seismic/acoustic sensing
- Condition-based maintenance, battlefield awareness, health monitoring, environmental monitoring, etc.



Product-Neutral Vacuum Packaging (Raytheon, et al.)

- Low-cost, mass-produced, high reliability
- Meets IR MEMS, RF MEMS, Inertial MEMS requirements
- Demonstrated <10 mTorr for 31 months, survived 10,000-g shock

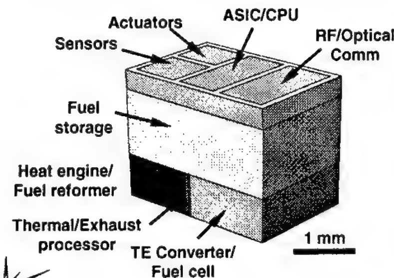


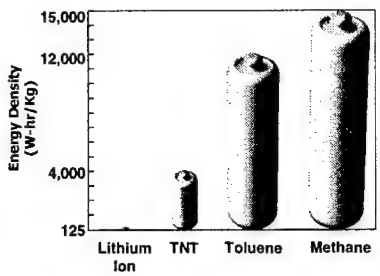
Wafer-level vacuum-packaged 120x160 α-Si microbolometer arrays

Microshell vacuum-packaged accelerometers, gyroscopes, & resonators

Micro Power Generation (MPG)

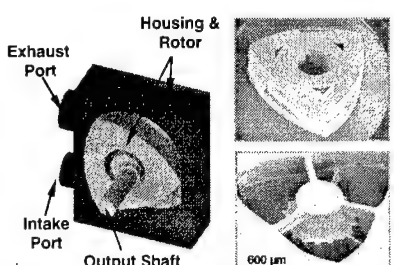
- Generate power at the micro scale to enable stand-alone micro sensors and micro actuators with wireless communication to realize new systems and strategies for weapons systems, processes, and battlefield environments.



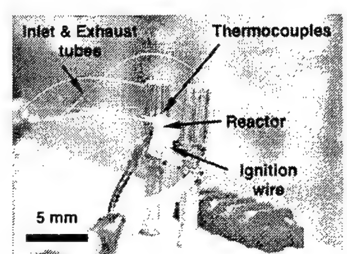


Microcombustion (UC Berkeley, Princeton, et al.)

- Demonstrated fabrication techniques of high-temp materials (SiC at UCB, alumina at Princeton).
- Demonstrated self-sustained combustion in 1 mm^3 chamber (H_2/Air, Princeton).



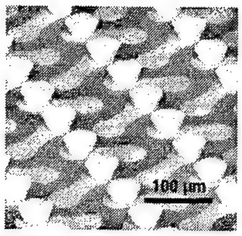
UCB Rotary Engine



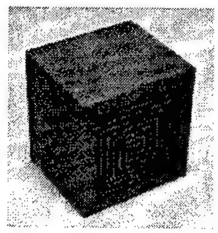
Alumina reactor with 200-µm-wide Pt-coated square channels (Princeton)

Thermoelectric Conversion (USC, et al.)

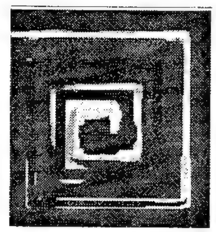
- Demonstrated counterflow Swiss-roll combustor
- Pursuing fabrication compatibility with thermoelectric elements (Bi_2Te_3)



USC/JPL micro TE elements



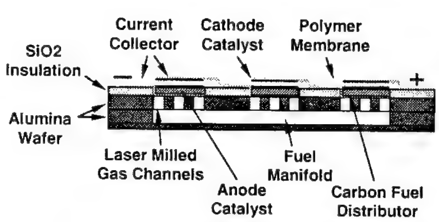
USC macro Swiss-roll combustor



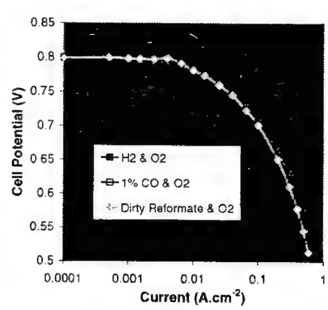
Simulation of combustion

Micro Fuel Cells (CWRU, et al.)

- Demonstrated fabrication of micro fuel cells with built-in super capacitor & PdH layer as H_2 source
- Demonstrated high-temperature (>130°C) fuel cell operation in the presence of CO



CWRU micro fuel cell with palladium hydride



The Future of MEMS at DARPA

- Continue existing commitment
  - Maturing projects
  - New thrust: Micro Power Generation
- Emphasize transition
  - Into DoD systems
  - Into industry
- Establish new programs
  - Programs enabled by MEMS

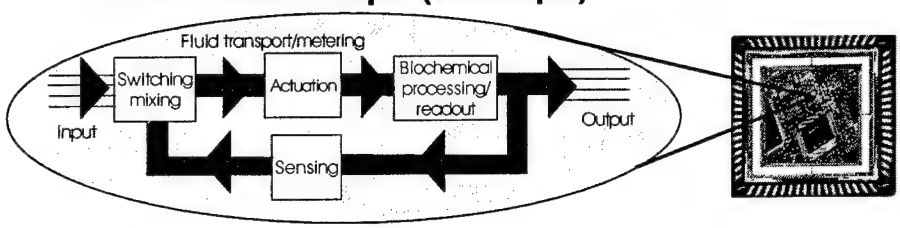
Bio-Fluidic Chips (BioFlips)

Abraham 'Abe' Lee, Program Manager

DARPATech 2000

September 6, 2000

Bio-Fluidic Chips (BioFlips)

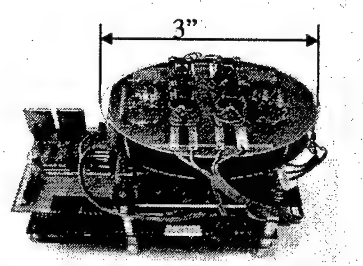


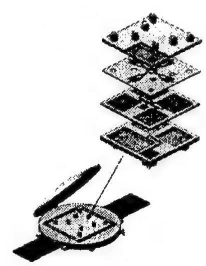
- ***Goal of Program***: Demonstrate integrated biofluidic microprocessor technologies capable of providing on-chip reconfiguration and self-calibration via feedback control

> The prototypes developed in this program will demonstrate biological fluid assay capability which will form the basis for the future goal of real-time, unobtrusive monitor and control of health parameters of the warfighter.

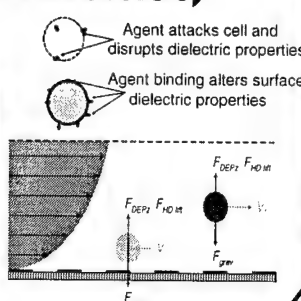
Bioflips - A Paradigm Shift from MicroFlumes

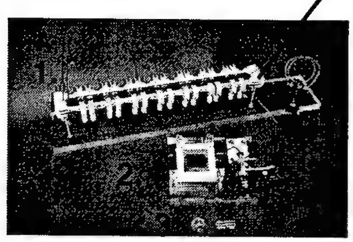
Microflumes	Bioflips
✦Discrete microfluidic components	✦Total integration platforms
✦Passive, fixed assays	✦Active, reconfigurable assays
✦CBD, non-disposable	✦Medical, disposable



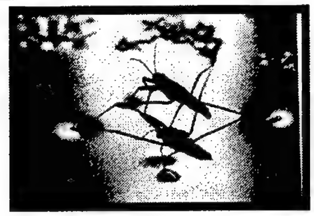


The Microfluidic Molecular Systems Program (MicroFlumes)





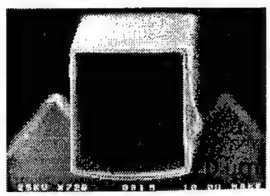
UTMDACC/
LLNL/Lynntech



"Versatility" of Microfluidics

✦ Miniaturized channels and reservoirs

- ➤ Increase speed of reaction
- ➤ Reduce cost of reagents
- ➤ Reduce power consumption
- ➤ High surface to volume ratio/low Reynolds number
- ➤ Precise mixing/dosage and heating



✦ Integration

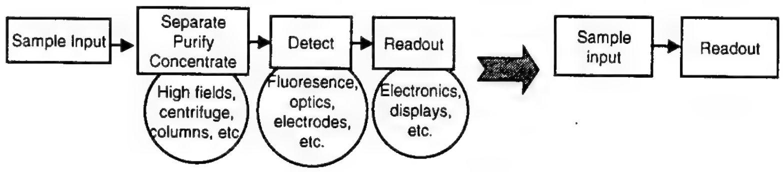
- ➤ Reduce cost of manufacture
- ➤ Minimize dead space, void volume
- ➤ Minimize sample carryover
- ➤ Multiplex capability: increased number of parameters monitored per assay

Integration Tasks and Technical Challenges

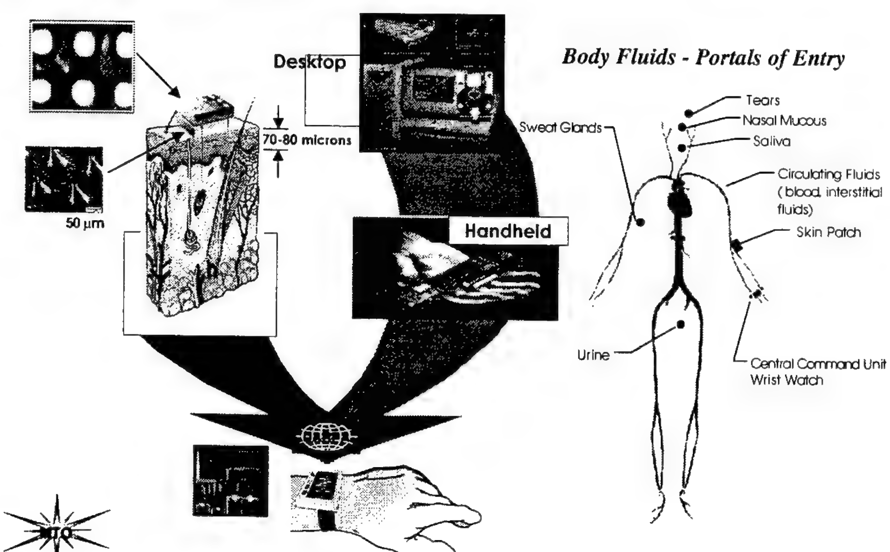
Technical Tasks	Challenges
1. Substrate processing for integrated fluidic transport and local flow control	Incompatible fabrication processes to integrate pumps, valves, channels, mixers, fluid sensors on single chips
2. Integrated fabrication of specific ligand receptors on passive and active surfaces	Incompatible fabrication conditions (temperature, sealing, patterning), surface conditioning and storage
3. Heterogeneous integration of disposable plastics with optical source/detector and electronics	Alignment, interconnection, optical components (e.g., lens), assembly
4. Integration of sample collection/delivery interface and sample storage	Sealing from contamination and pressure leakage, fabrication of protruding needles, z-direction flow control
5. Prototype integration and demo	Integration of fluidic and electronic interconnects; power consumption

Technical Approach: Sample-to-Readout Multi-functional Micromachining Platforms

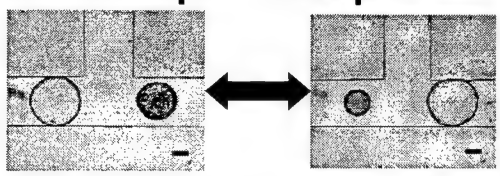
Enable the chip designer to design an integrated system meeting specific application specifications (analogous to CMOS for integrated circuits).



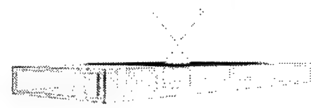
Bioflips Enables Ubiquitous Sampling, Analysis, and Synthesis of Biofluidics



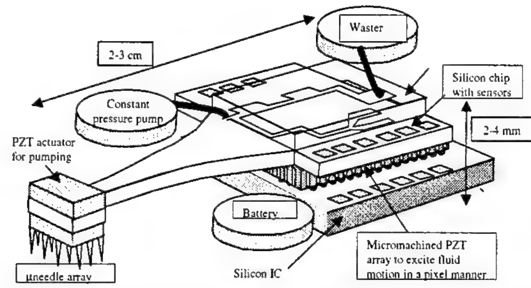
Two BioFlips Examples



U.Wisconsin/UIUC



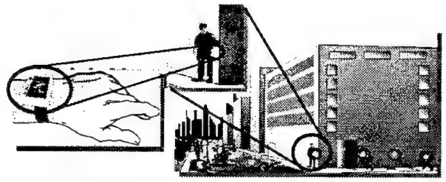
In situ polymerized/patterned/functionalized components



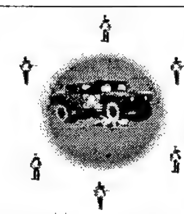
U.Wisconsin

Piezoelectric micromachining platform for BioFlips

Wrist-Mounted BioFlips



Distributed



Central Units

It should be possible to detect a presymptomatic infection within the first hour by a cytokine profile

Commercial Applications
- Quick assessment of contaminated water and food sources
- On-demand chemical and drug synthesis
- Antidote delivery, swallowable and implantable chips
- Out patient care for high risk and chronically-ill patients

DoD Application
- Distributed, covert deployment of bio-detectors
- Rapid indication of CBW incident
- Indication of extent of problem and overall effect
- Battlefield triage information for medic
- Human responses during testing
- Performance enhancement drug delivery

Design of Integrated Mixed Technology Microsystems

Anantha Krishnan

Microsystems Technology Office
DARPATech
September 2000

Technology Trends

- SYSTEM COMPLEXITY IS INCREASING !!
- DESIGN AND PROTOTYPING COSTS ARE INCREASING AT A GREATER RATE (TRIAL & ERROR APPROACH) !!
- INTUITION AND 'EXPERIENCE' ARE JUST NOT GOING TO CUT IT !!

NEED CAD TOOLS TO SIMULATE AND PREDICT SYSTEM PERFORMANCE BEFORE PHYSICAL PROTOTYPING IS DONE !!

Design Approach

Today, mixed technology "systems" are developed from the "bottom up" using many different components

SYSTEM

↑

SUB-SYSTEM

↑

COMPONENT

Ad-hoc Design, Research Codes, Single User Tools

Design Approach

Future mixed technology systems must be designed from the "top down" using a consistent set of requirements

SYSTEM

↓

SUB-SYSTEM

↓

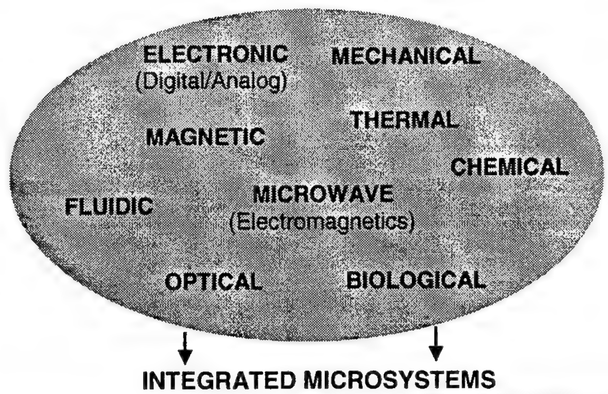
COMPONENT

Methodology, Design Rules and Checks, Multi-User Tools

Goal is to provide VLSI-like Design Tools for Integrated Mixed Technology Systems

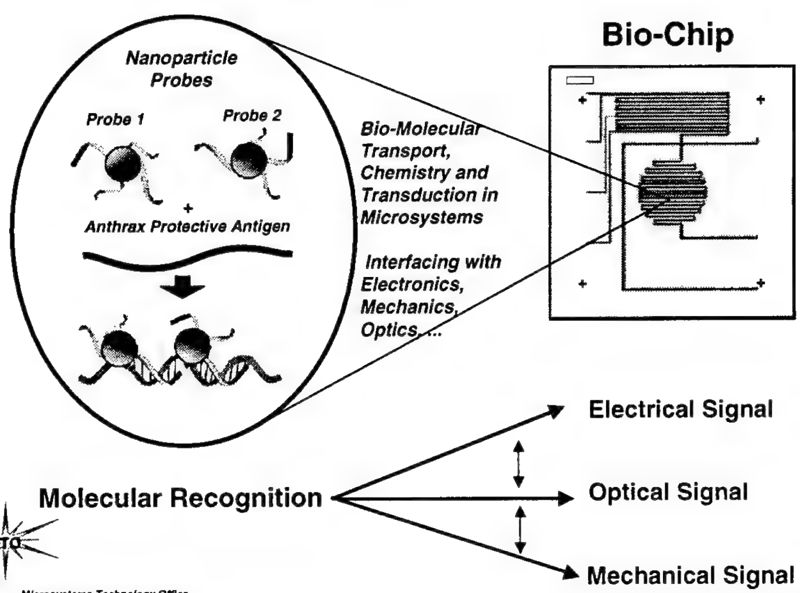
Integrated Microsystems

- **Microsystem technology is much more complex due to interaction of mixed technologies - electronics, mechanics, optics, fluidics, chemistry, biology, ...**
- **But same analogy holds: Microsystem-EDA essential for growth of integrated system technology !**



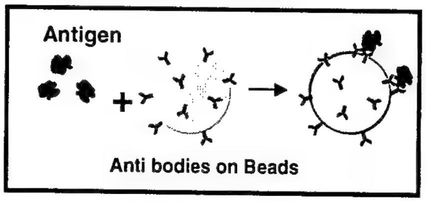
Adapted from David Nagel, Naval Research Laboratory

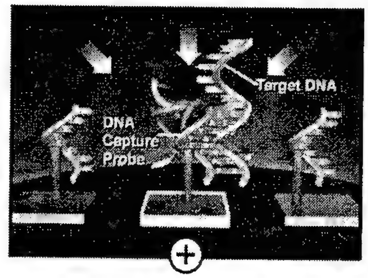
Biological/Chemical Sensor Systems

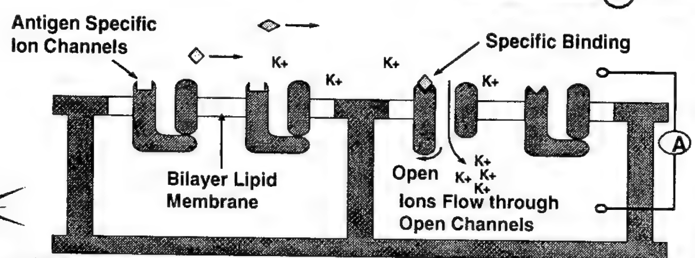


Molecular Recognition

- **Development of models for bio-molecular interactions in microsystems**
  - Time Scale of Process

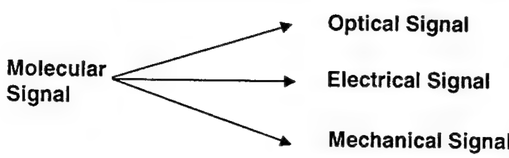


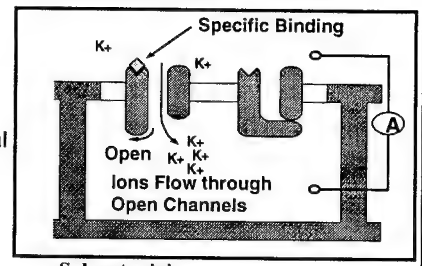


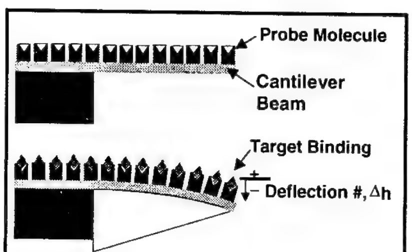


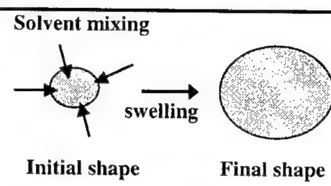
Signal Transduction

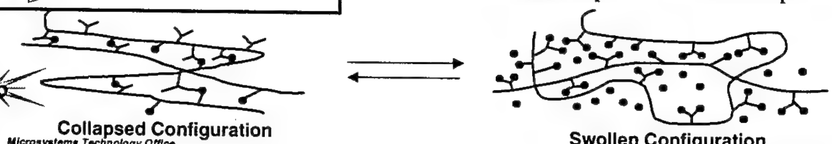
- **Development of models for the transduction process**





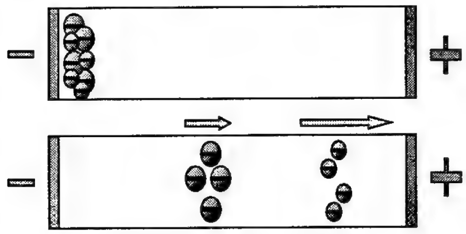




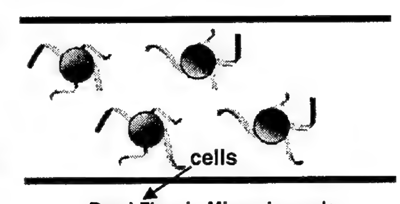


Microfluidics

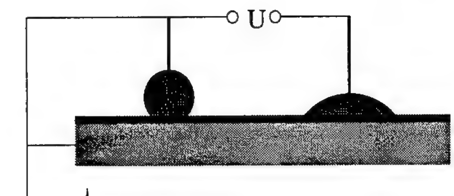
- Models for Bio-Molecular and Fluidic Transport



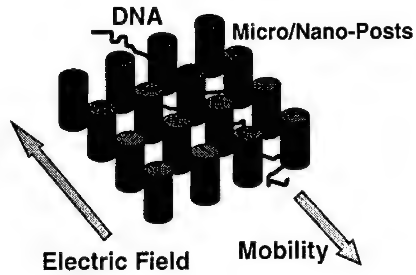
Electro-osmosis + phoresis



Bead Flow in Microchannels



Surface Tension Driven Transport

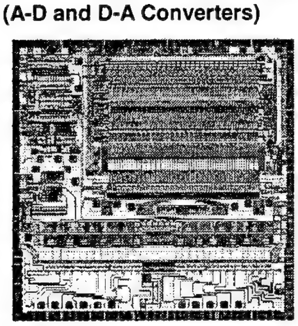


Microsystems Technology Office

Electronic and Photonic Systems

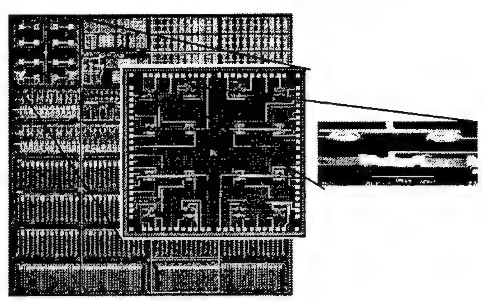
Mixed Signal (Analog-Digital) Systems

Advanced Digital Receiver Chip
(A-D and D-A Converters)



Mixed Electronic/Photonic Systems

Integrated VCSEL-Detector Arrays

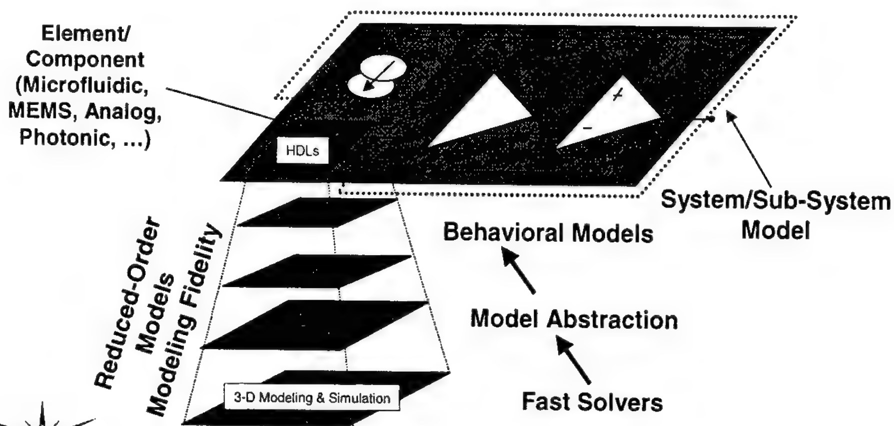


Lack of Automated Design Methodologies; More of an ad-hoc approach

Microsystems Technology Office

Integrated System Analysis

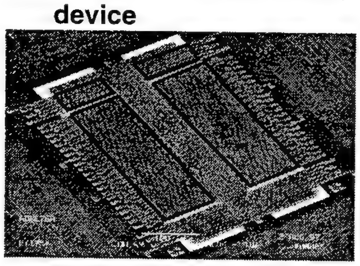
- Development of reduced models and integrated system models for mixed technology microsystems



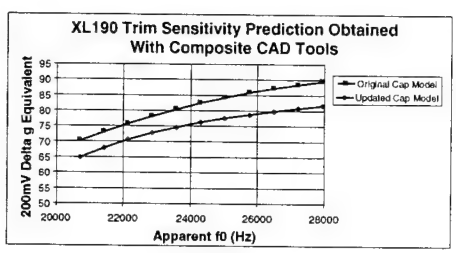
Linear as well as Non-Linear Systems !

Demonstration of Mixed Technology Design – Example 1

- Reworking the (Analog Devices) 50g Sensor into a 190g device

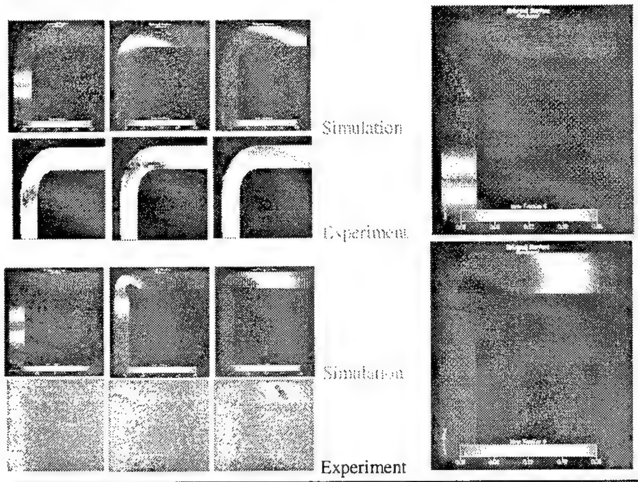


Full 3D simulation improved trim yield by 20% because of better sensitivity prediction.



- Accurate calculation of the trim factors for this particular device was only possible using the 3D electromechanical (Composite CAD) tools
- The trim factors are essential in order to trim the device accurately. Without the simulations, AD would not have a product.

Demonstration of Mixed Technology Design – Example 2

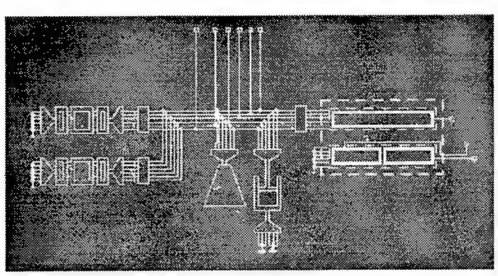


Stanford Microfluidics Laboratory

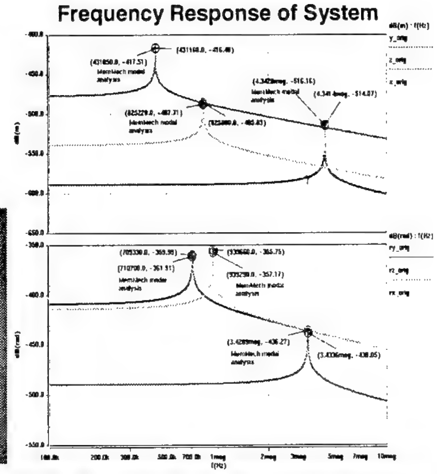
- **Simulation enabled development of a new design that minimizes dispersion in a miniaturized electro-osmosis process !!**

Demonstration of Mixed Technology Design – Example 3

Microcosm Tech.



Frequency Response of System



- **Model reduction enabled orders of magnitude reduction in simulation cost without sacrificing model accuracy !!**

Focus Areas

✦ Quantitative models (scaling relationships and phenomenological models) for microfluidic devices, MEMS, photonic components, etc.

✦ Model abstraction/reduction and integration at the microsystem scale - **Integrated System Analysis**

Capability to design microsystems with a high level of multi-disciplinary integration – Enabling technology for exponential growth !!

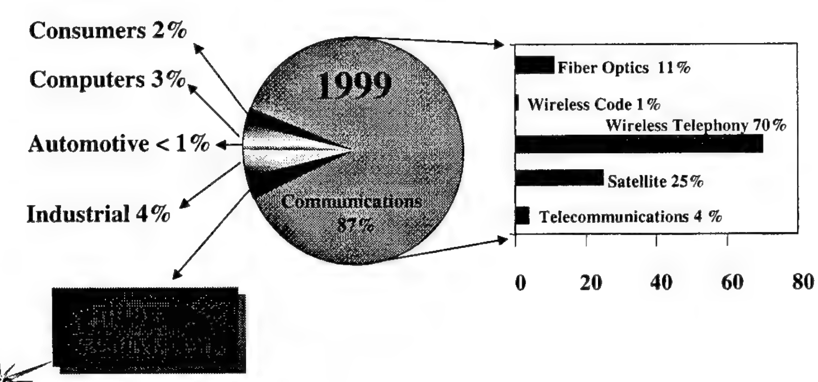
Gallium Nitride & Related Wide Bandgap Materials and Devices

Dr. Edgar J. Martinez
Program Manager

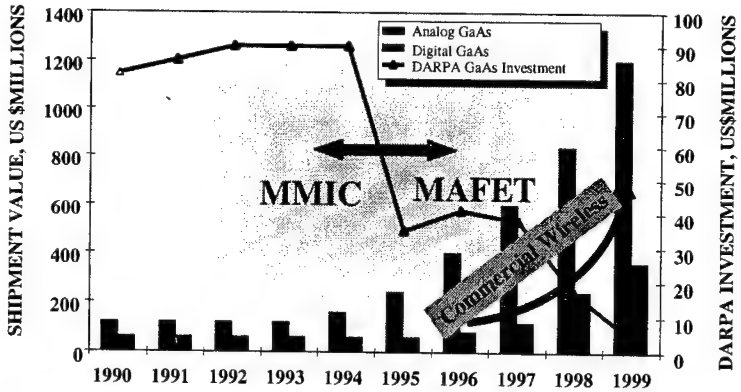
DARPATech 2000

GaAs IC Markets

1999 Market $11 Billion
2005 Market $20 Billion



GaAs IC Market 1990-1999

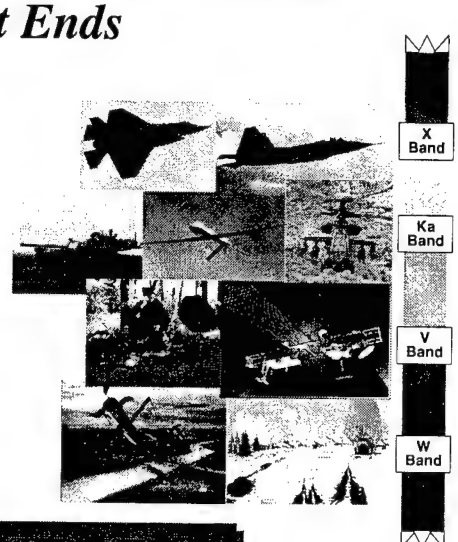


Yesterday's [illegible] designs
Today's commercial reality

Microsystems Technology Office

Unmet Challenges in RF Analog Front Ends

- ❖ Power Density > 1 W/mm
- ❖ Multi-octave Bandwidth
- ❖ High Efficiency > 50%
- ❖ Linearity
- ❖ Low Noise Figures
- ❖ Low Phase Noise



Future DARPA Focus

Microsystems Technology Office

Electronic Properties of Semiconductor Materials

	Si (----)	GaAs (AlGaAs/ InGaAs)	InP (InAlAs/ InGaAs)	4H SiC (----)	GaN (AlGaN/ GaN)
Bandgap (eV)	1.1	1.42	1.35	3.26	3.49
Electron mobility (cm^2/Vs)	1500	8500	10000	700	900
Saturated (peak) electron velocity ($x10^7$ cm/s)	1	2.1	2.3	2	2.7
2DEG sheet electron density (cm^{-2})	NA	$<4 \times 10^{12}$	$<4 \times 10^{12}$	NA	$20x10^{12}$
Critical breakdown field (MV/cm)	0.3	0.4	0.5	2	3.3
Thermal conductivity (W/cm-K)	1.5	0.5	0.7	4.5	>1.7
Relative dielectric constant (εr)	11.8	12.8	12.5	10	9.0

[redacted]

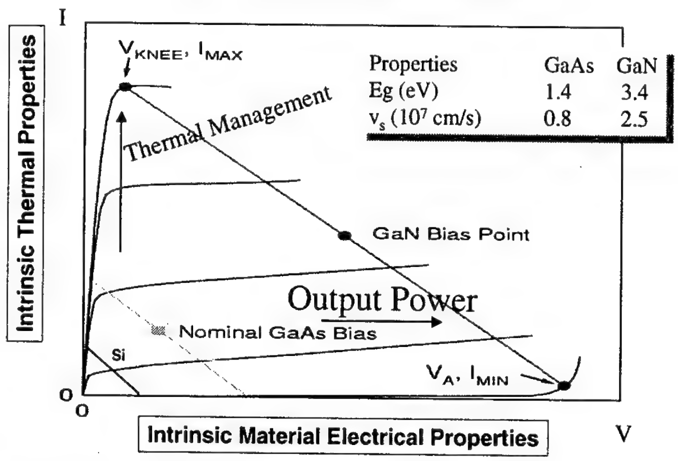
[illegible] provide the power-bandwidth product for military applications

III-N Material Challenges

- ❖ **Substrates difficult to produce**
- ❖ **High temperature material growth process**
- ❖ **Defect rampant**
- ❖ **Low hole mobility**
- ❖ **Deep donors and acceptors**

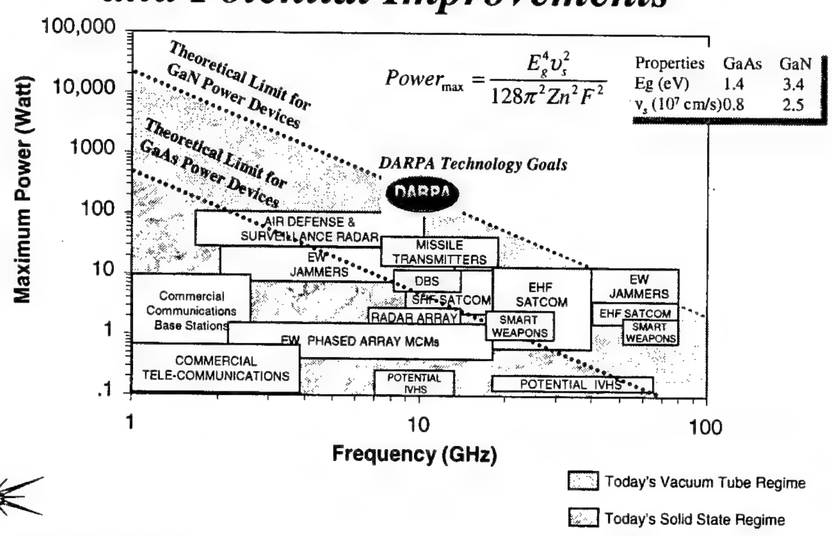
Limitations of Today's Solid-State Devices

FET Microwave Output Power



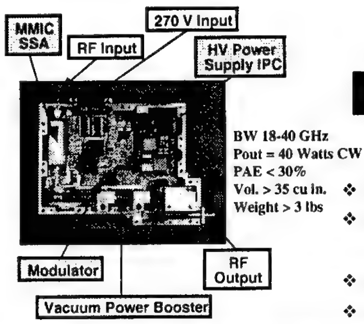
$P_{out} = (\Delta I \times \Delta V)/8$

Current Technology Limitations and Potential Improvements



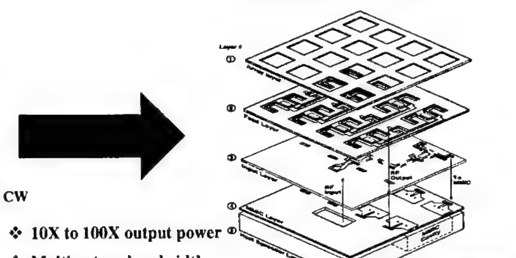
GaN - A Disruptive Technology

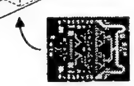
State-of-the-art Microwave Power Module



BW 18-40 GHz
Pout = 40 Watts CW
PAE < 30%
Vol. > 35 cu in.
Weight > 3 lbs

Future RF Single Power Chip in an Advanced Package





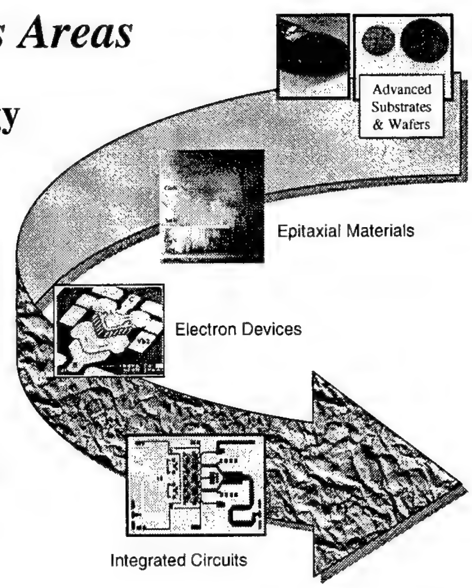
GaN PAmp

- ❖ 10X to 100X output power
- ❖ Multi-octave bandwidth operation
- ❖ >35X reduction in volume
- ❖ >50X reduction in weight

[illegible]

WBG Compound Semiconductors Focus Areas

- ❖ **Material Technology**
  - ➢ **Bulk Crystal**
  - ➢ **Epitaxial Materials**
- ❖ **Device Technology**
- ❖ **Thermal Control & Packages**



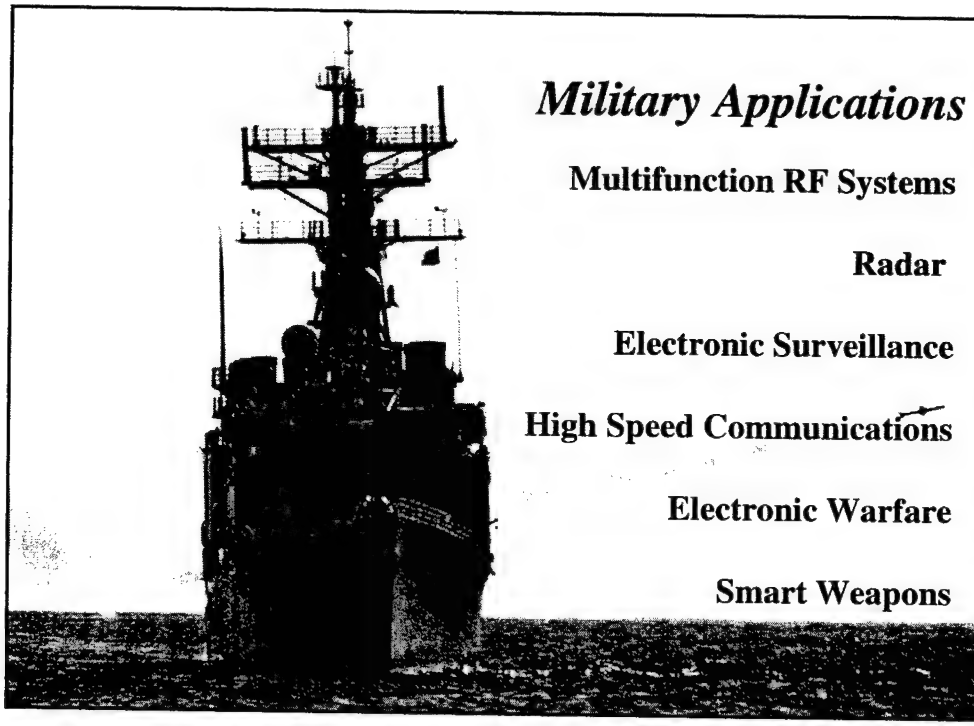
Technical Strategy

Comprehensive Effort is Required for Development of Robust Technology

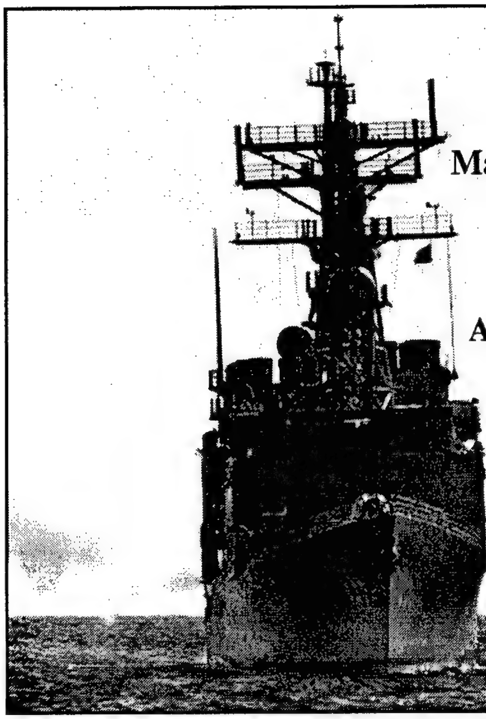
- System Performance
- MMIC Performance
- Packaging & Thermal Management
- Device Performance
- Material Properties & Parameters

- **Apply Knowledge & Experience from GaAs MMIC Community**
- **Leverage from Emerging GaN Commercial Developments – Economies of Scale**

Microsystems Technology Office



System Benefits

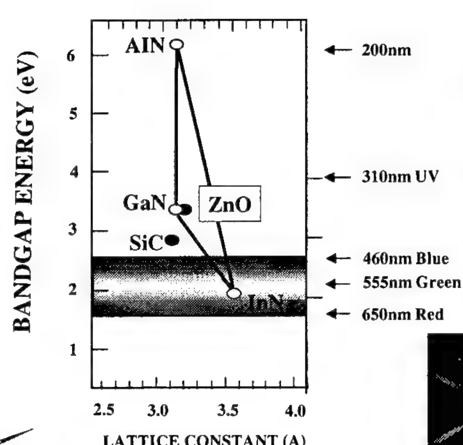


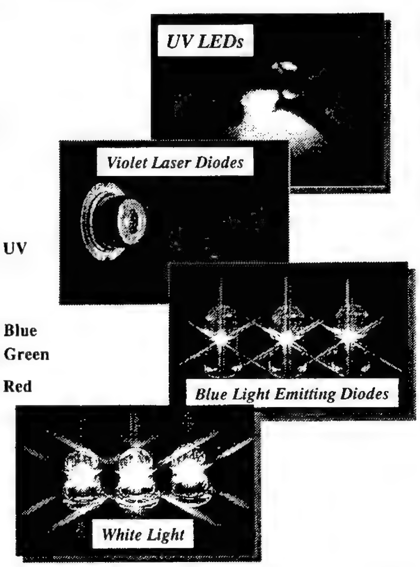
Maximizes bandwidth utilization for multifunctionality

Ability to track targets in heavy clutter or in the presence of enemy jamming

Reduced system size, cooling requirements, and cost

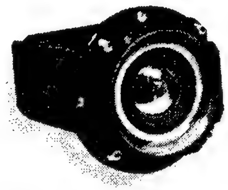
WBG Semiconductors' Optical Benefits





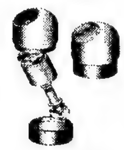
UV Solar Blind Detectors & Current and Future Missile Warning Systems

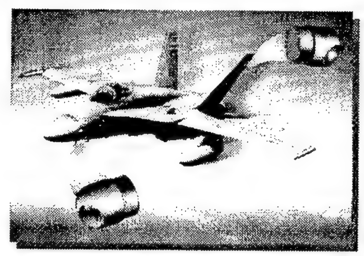
- Ground vehicle self protection
- Airborne missile threat warning
  - AAA/MG detection and estimation
  - UV search and track
- Biological agent detection
- Engine monitoring
- Combustion control



AN/AAR-47 Ultraviolet
Helos Transports

AN/AAR-57
Ultraviolet
Helos Transports
Tactical

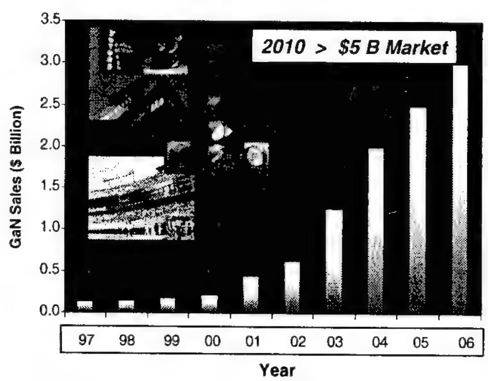




Today's Technology
Bulky, Fragile and Expensive

Commercial Opportunities for GaN

- Traffic lights
- Illumination
- Automotive
- Medicine
- Outdoor displays
- Mass data storage
- Wireless communications



Data Source: Strategies Unlimited 1997

Summary

- ❖ **GaN enabling technology for many military applications**
- ❖ **Many material and device challenges**
- ❖ **Technical strategy requires comprehensive development efforts with many industry and academia partnerships**
- ❖ **Significant system benefits anticipated**
- ❖ **Commercial interest will not meet military needs**

DARPA is in the process of creating new opportunities with WBG semiconductors

MTO

DARPA

Tactical Technology Office Programs

DARPATech 2000

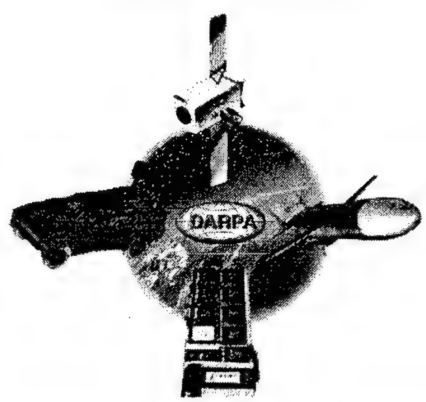
Dr. David Whelan
Director

dwhelan@darpa.mil

Tactical Technology Office

Global Surveillance

Land Systems



Aerospace Systems

Embedded Processing & Control

Global Surveillance

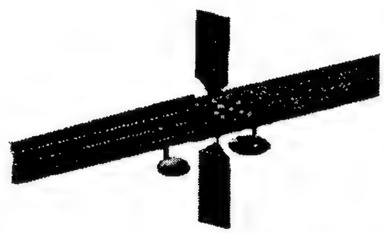
Objectives:
- Birth-to-Death Track
- Moving Target ID

Enabling Technologies:
- Space-Time Adaptive Processing
- Thinned ESA Antennas
- Low Power Processors
- Geographic Data Bases

Challenge:
- "Eyeball-on-Target" from Space

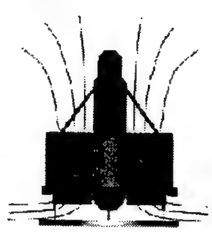
New Efforts:

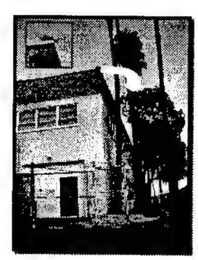
Coherent Communications, Imaging and Targeting



Agile Space-Based Radar Validates Birth to Death Tracking of Ground Targets

Micro Air Vehicles



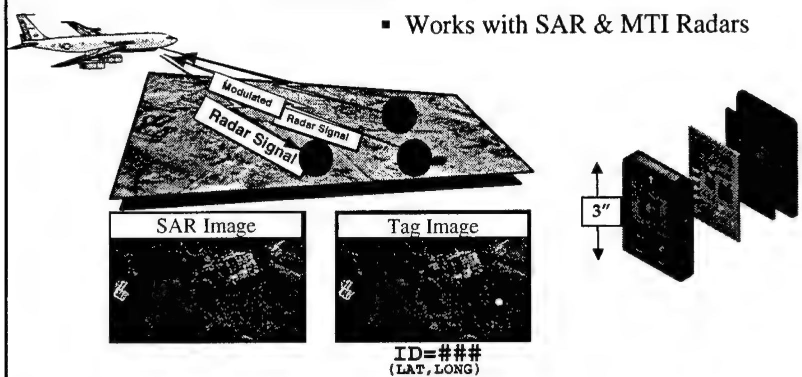


Technical Challenges:
- Increase endurance/payload
- High wind operation
- Perch/stare
- Operate under canopies

Accomplishments:
- Successful flight tests
- Full motion video
- Miniature IMU

Digital RF Tags Program

- C^3 Information Embedded in Radar Signal Modulation
- High Bandwidth Communications Capability
- Works with SAR & MTI Radars



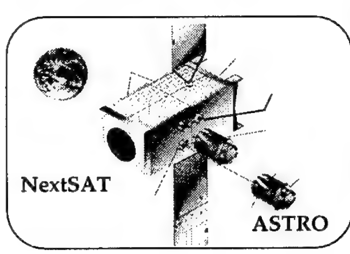
Aerospace Systems

Objectives: Prompt Precision SEAD
Space Force

Challenge: Tactical Maneuvering Satellites

Enabling Technologies:
- Autonomous Control
- Active Aerodynamics
- Flow Manipulation
- High Strength Materials for Airfoils

New Efforts:
- **Supersonic Miniature Air-Launched Interceptor**
- **UCAV-N**

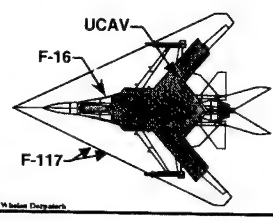


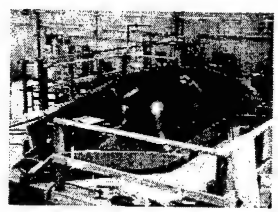
Orbital Express

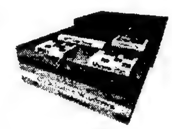
Unmanned Combat Air Vehicle

A Revolution in Air Power:
- 4:1 vehicles per operator
- Dynamic mission replanning
- 20% of current O&S costs
- Affordable stealth to the next level
- AT3 & onboard SAR targeting
- Flexible transporter
- Self-deployment
- *1/3 of JSF cost*

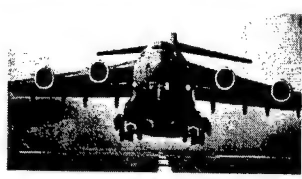
Program Status:
- Initial demonstrations successful
- Toolkit under construction
  - System Integration Laboratory online
  - MCS software build in work
  - Air vehicles & containers being built
- T-33 Surrogate UCAV flies this summer
- First UCAV flies next Spring



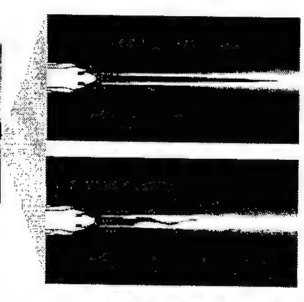


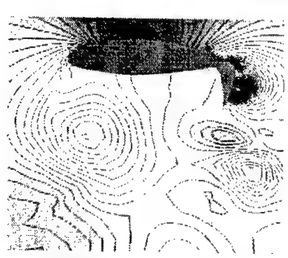


Micro Adaptive Flow Control

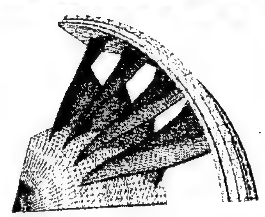


C-17 Active Control of Exhaust





Advanced CFD Codes



Aspirated Compressor Blades

Hummingbird A160

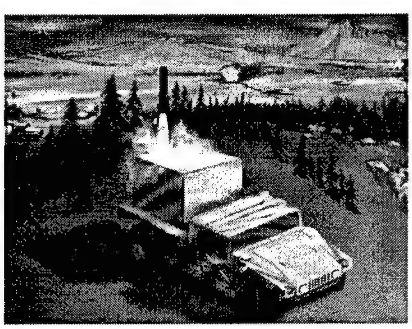
- **Demo Advanced Rotorcraft Technology**
  - Advanced hingeless rotor design
  - Reduced acoustic signature
- **Significant Increase in VTOL Range & Endurance**
  - 3000 nautical mile range with surveillance payload
  - 30-48 hours endurance

High Capability Surveillance Payloads
- SAR/MTI Radar
- EO/IR Search/Designator
- FOPEN Radar
- ELINT

Land Systems

Objectives:
Faster Deployment
Reduced Logistics

Enabling Technologies:
Unmanned Vehicles
Networked Remote Fires



Net Fires

Challenge:
Distributed Functions

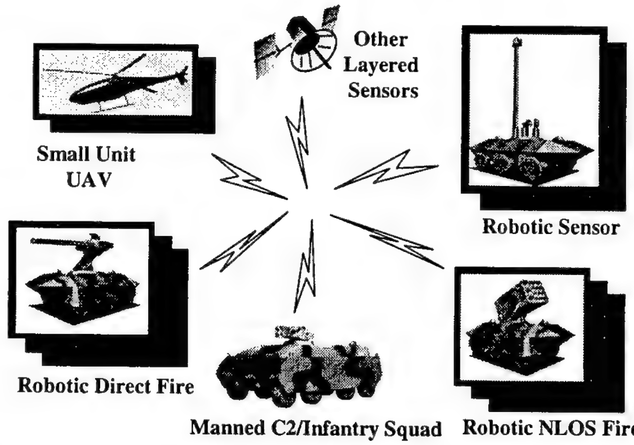
New Efforts:
Future Combat System

DARPA

Future Combat Systems

Network Centric Force

TTO



DARPA

Embedded Processing and Control

TTO

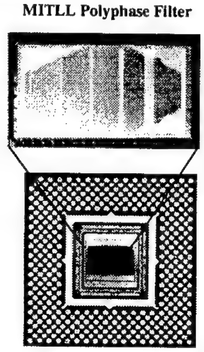
Objectives:
- Multi-Sensor Organic Processing/Fusion
- Real-Time Response

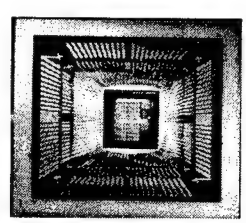
Enabling Technologies:
- Bit Systolic Processing
- Wideband Space-Time Adaptive Processing

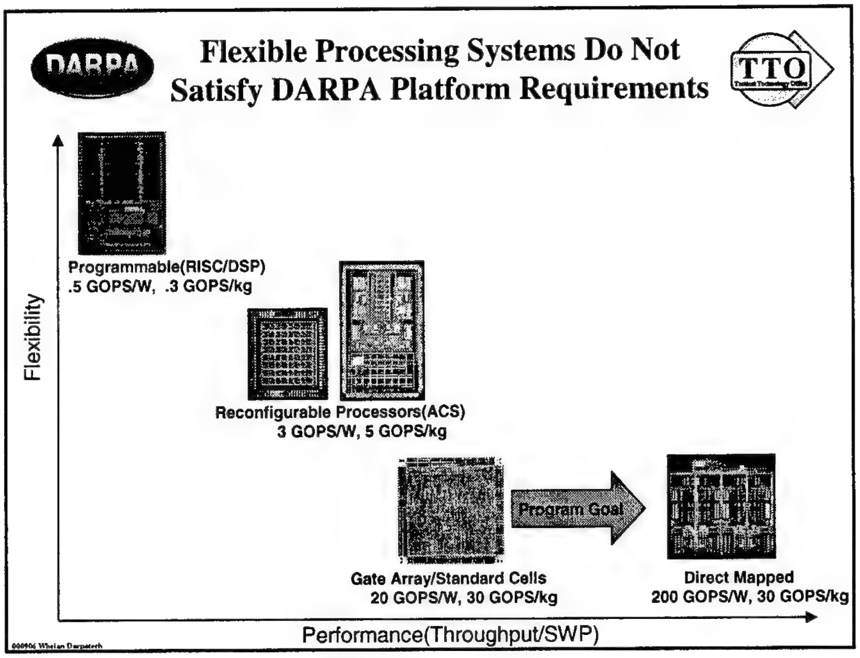
Challenge:
- Mission Specific Processors (Throughput/Power)

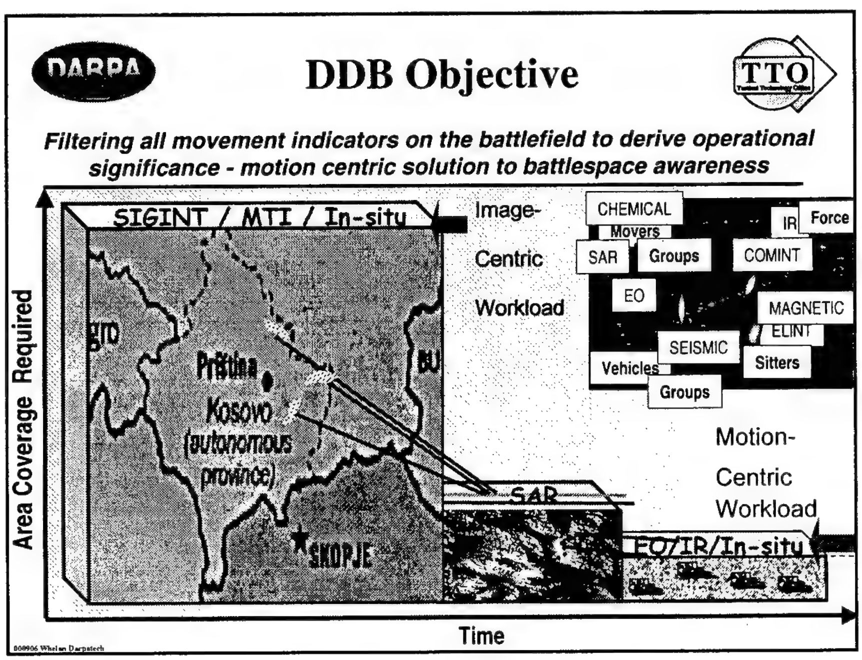
New Efforts:
- **Mission Specific Processors**

MITLL Polyphase Filter






DARPA
Flexible Processing Systems Do Not Satisfy DARPA Platform Requirements
TTO
Flexibility
Programmable(RISC/DSP)
.5 GOPS/W, .3 GOPS/kg
Reconfigurable Processors(ACS)
3 GOPS/W, 5 GOPS/kg
Program Goal
Gate Array/Standard Cells
20 GOPS/W, 30 GOPS/kg
Direct Mapped
200 GOPS/W, 30 GOPS/kg
Performance(Throughput/SWP)


DARPA
DDB Objective
TTO
Filtering all movement indicators on the battlefield to derive operational significance - motion centric solution to battlespace awareness
SIGINT / MTI / In-situ
Image-
Centric
Workload
CHEMICAL
Movers
IR
Force
SAR
Groups
COMINT
EO
MAGNETIC
ELINT
SEISMIC
Sitters
Vehicles
Groups
Priština
Kosovo
(autonomous
province)
SKOPJE
Motion-
Centric
Workload
SAR
EO/IR/In-situ
Area Coverage Required
Time

DARPA

Video

TTO

Football thrown past crowd in background

DARPA / Department of the Navy

Naval Unmanned Combat Air Vehicle

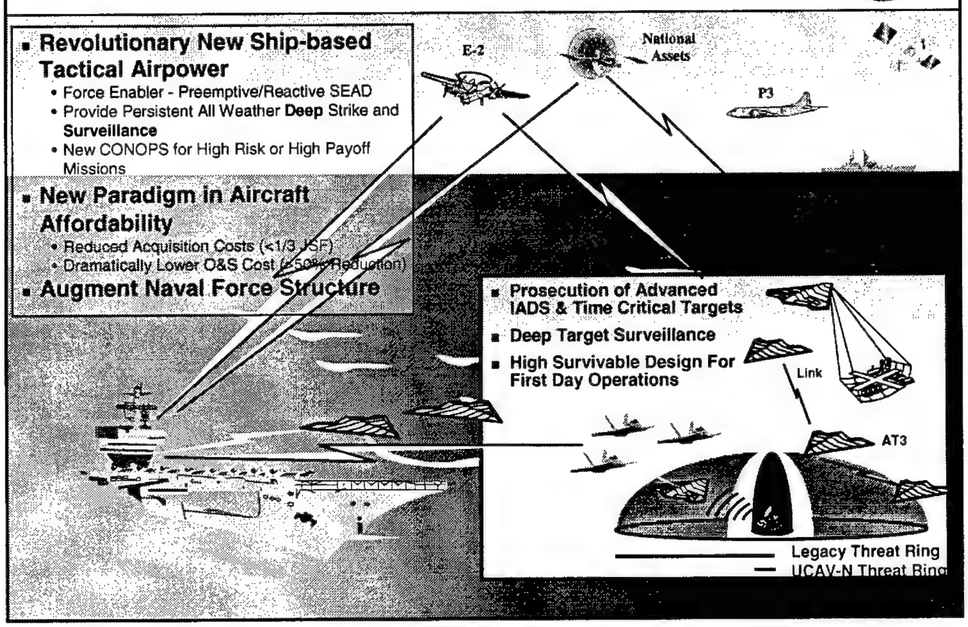
(UCAV-N)

Advanced Technology Program

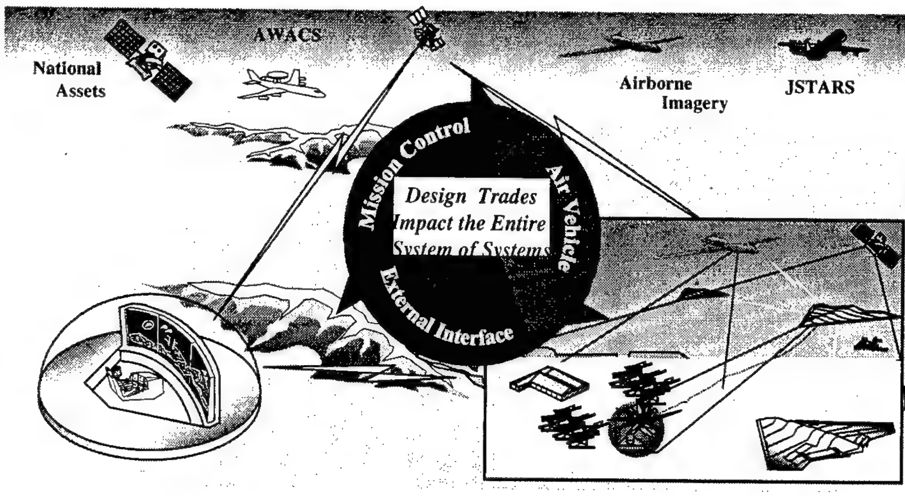
DARPATech 2000

Dr. William Scheuren
DARPA/TTO
wscheuren@darpa.mil (703) 696-2321

UCAV-N Vision



System Concept



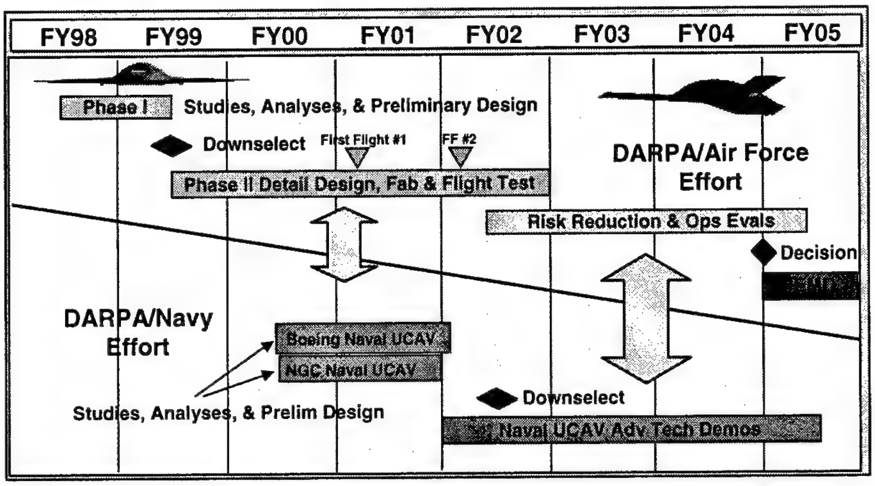
07/21/97

System Themes

- **Network Centric Warfare**
- **Revolutionary Mission Control System Potential**
  - Operators at the center of information
  - Intelligent decision aids
  - Teams control swarms
- **Revolutionary Air Vehicle Potential**
  - End-node of a lethal system
  - High degree of on-board intelligence
  - Product of latest design/manufacturing tools
  - Tailored yet robust capabilities
  - Minimal maintenance/high sortie rate
- **All Technologies Buy Their Way onto the System**
- **Lowest Mission Cost per Target Kill**

07/21/97

UCAV & UCAV-N Acquisition Plan



07/21/97

Program Philosophy

- Partnership to Demonstrate Technical Feasibility
- Exploit Design Freedom
- Think Out of the Box
- Mission Focus but Not a Point Solution
- Exploit UCAV ATD
- Focus on Naval Unique Environment/Issues
- Advanced Technology NOT an Acquisition Program
- Seamless Path to EMD Decision
- Provide Focus for S&T

07/21/97

Goal & Objectives

Demonstrate the technical feasibility for a UCAV system to effectively and affordably prosecute persistent, sea-based 21st century SEAD/Strike/Surveillance missions within the emerging global command and control architecture.

- Develop
  - A low life-cycle cost, mission effective sea-based design for a SEAD/Strike/Surveillance unmanned air vehicle
  - A reconfigurable control system for multi-vehicle operations in Naval environments
  - Robust/secure command, control & communications, including line-of-sight and over-the-horizon
- Evaluate
  - Human computer function allocation, dynamic mission planning & management approaches
  - Off-board/on-board sensor integration, weapon targeting & loadouts
- Demonstrate
  - Naval operations including ship launch and recovery, deck handling and storage, maintenance and training, and interoperability with other Naval aviation systems and operations
  - Human-in-the-loop, detection, identification, location, real-time targeting, weapons authorization, weapons delivery and target damage indication

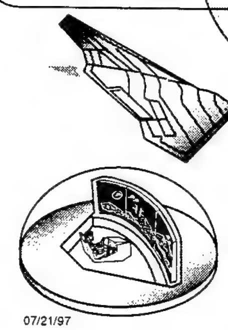
07/21/97

Program Approach
UOS Focuses SMP

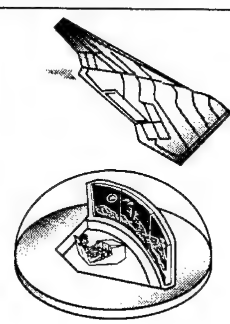
Analyze High Payoff Missions

Naval UCAV Operational System (UOS-N)
- Effective & affordable weapon system for post 2010 missions
- Product of multi-dimensional / optimized trade studies
- Designed to identify the critical technologies, processes & System Attributes (TPSAs)

System Maturation Plan (SMP)
- Complete roadmap of TPSA risk reduction activities including cost and schedule to achieve UOS-N vision
- Naval UCAV Demonstrator System (UDS-N) is fundamental component of the SMP
  - Maintains direct legacy to UOS-N
  - Focused by UOS to address critical TPSAs, explore CONOPS design space & validate UOS key assumptions



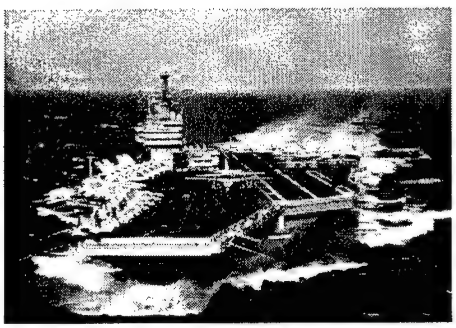
Technologies Processes & System Attributes (TPSAs)
- Shipboard Integration
- Command / Control / Communications (C^3)
- Targeting / Weapons Delivery
- Supportability/Health Mgmt
- Human-Systems Interaction
- Signature
- Air Vehicle



07/21/97

UCAV-N Technical Challenges

- Focus on Naval unique technology and integration issues
- Leverage DARPA / USAF UCAV Program



- **Ship Suitable UCAV Design**
  - Size, weight, costs for ship design
  - Speed, stability and control of LO design
  - Cat/Trap vs. alternatives (e.g. V/STOL)
  - Maritime environment issues
  - Safety
- **Mission Control Integration**
  - Autonomous launch & recovery
  - Integrated deck operations
  - Shipboard interfaces
  - Integration With Navy C4ISR assets
  - EMI/EMC environment
- **Naval CONOPS**
  - SEAD / Deep Strike / Surveillance
- **Affordable Naval Operations & Support**
  - Storage transport
  - Training
  - Rapid turnaround, maintenance

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Phase I Products

- Trade Study Results
- Alternative CONOPS Analysis
- UCAV-N Operational System Design (UOS-N)
- UOS-N Effectiveness & Affordability Analysis
- System Maturation Assessment (SMA)
- UCAV Demonstration System (UDS-N) Requirements

Naval Focus

Goal is to Demonstrate That Proceeding into Phase II is Justified and can be Accomplished within Cost & Schedule

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Program Approach
Organization

- **Phase II**
  - Wide range of options
    - Full scale advanced technology demo like UCAV ATD
    - Conduct Naval unique aspects of SMP
    - Anywhere in-between
  - Continue to refine effectiveness/affordability projections
  - Provide best value to the government
  - Additional information available with MS 2 feedback
- **RR&OE**
  - Focus shifts to operational utility & military value
  - Completes seamless path to EMD

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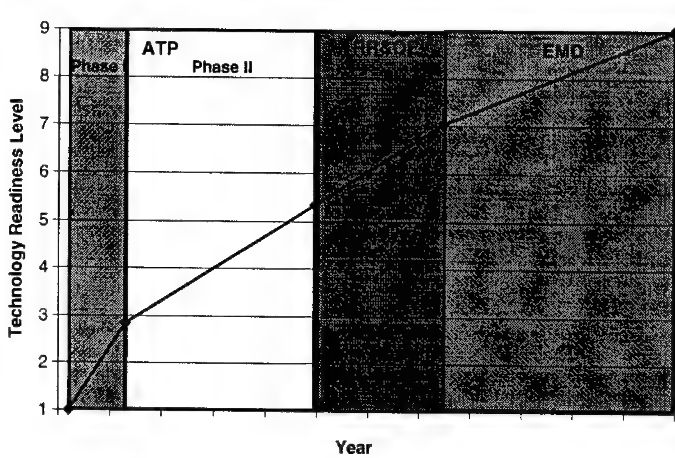
Program Approach
Technology Readiness Level Perspective



Technology Readiness Levels

9 "Flight Proven" through successful mission objectives
8 "Flight Qualified" through test & demonstration
7 Prototype demonstration in an operational environment
6 System/Prototype demo in a relevant environment
5 Component validation in relevant environment
4 Component validation in laboratory environment
3 Analytical, experimental or characteristic proof of concept
2 Technology concept/ application formulated
1 Basic principles reported

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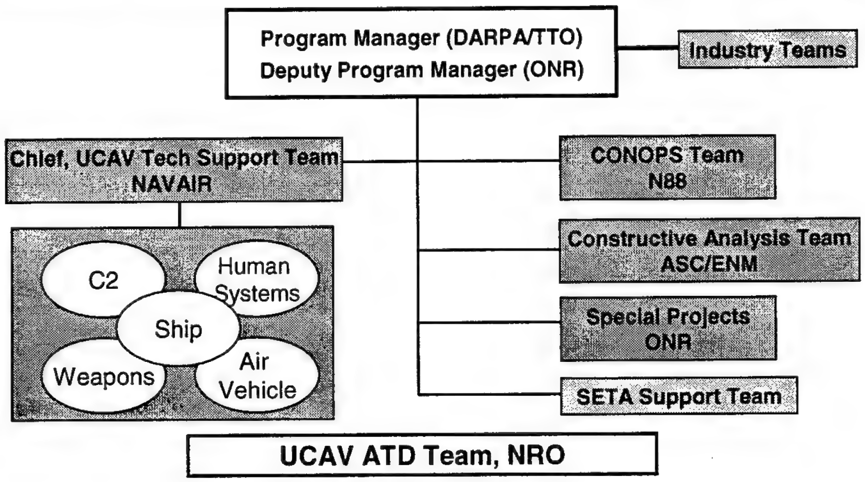
Management Structure



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Summary

- Naval UCAV program
  - –Meets high priority Naval needs
  - –Technology and program opportunities exist
  - –Potential revolutionary payoffs
- Phase I underway
  - –Boeing and Northrop Grumman selected
- Phase II
  - –Funding identified
  - –Execution contingent on successful Phase I outcome
  - –Draft solicitation out to industry for comment

07/21/97

Future Combat Systems

DARPATech 2000

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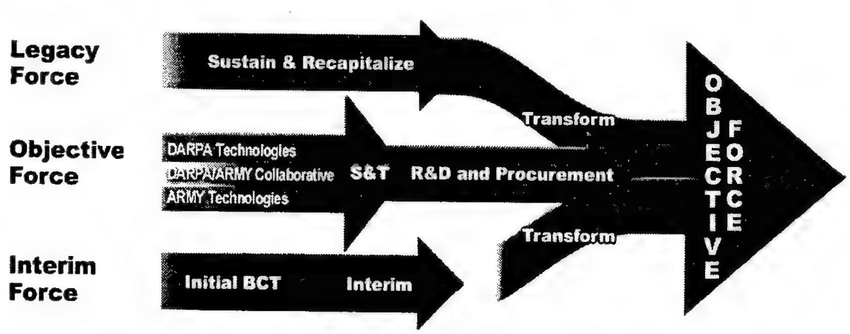
What is the FCS Program?

- **The Future Combat Systems (FCS) Program is a collaborative program between the Defense Advanced Research Projects Agency (DARPA) and the US Army to provide for the evaluation and competitive demonstration of the Future Combat Systems.**
- **The FCS Program will:**
  - Define and validate FCS design/operational concepts using modeling and simulation and surrogate exercises
  - Develop key enabling technologies for distributed lighter forces
  - Fabricate and test a multi-mission FCS Demonstrator suitable for EMD and production

FCS Program Structure

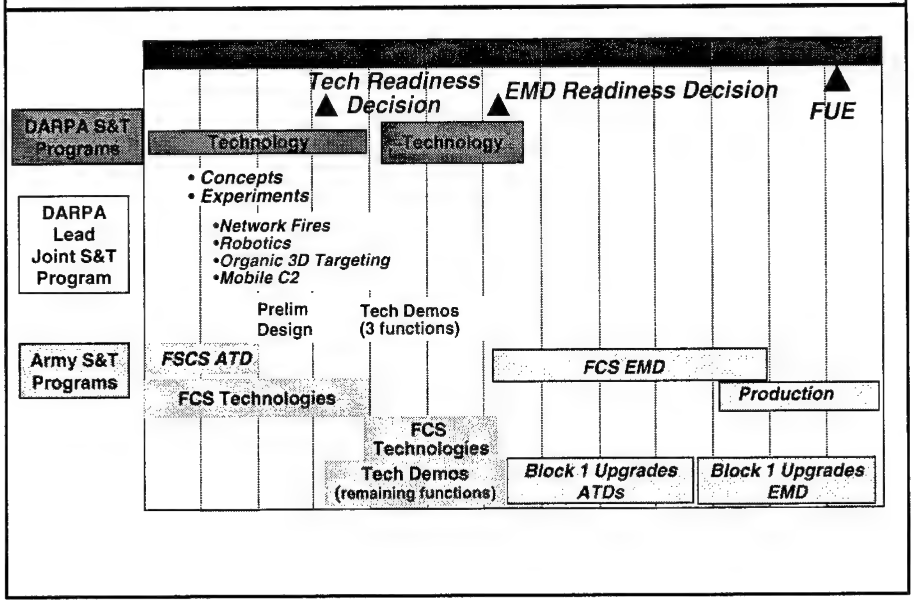
- Structured to support the vision of the Objective Force.
- Contains the key elements representing the user, the technologist, and the developer.
- Built around a core team to execute the program.
- Supported by directly related DARPA risk reduction initiatives, Army S&T and a TRADOC TSM.
- Structured to share information and encourage Team innovation.

The Army Transformation

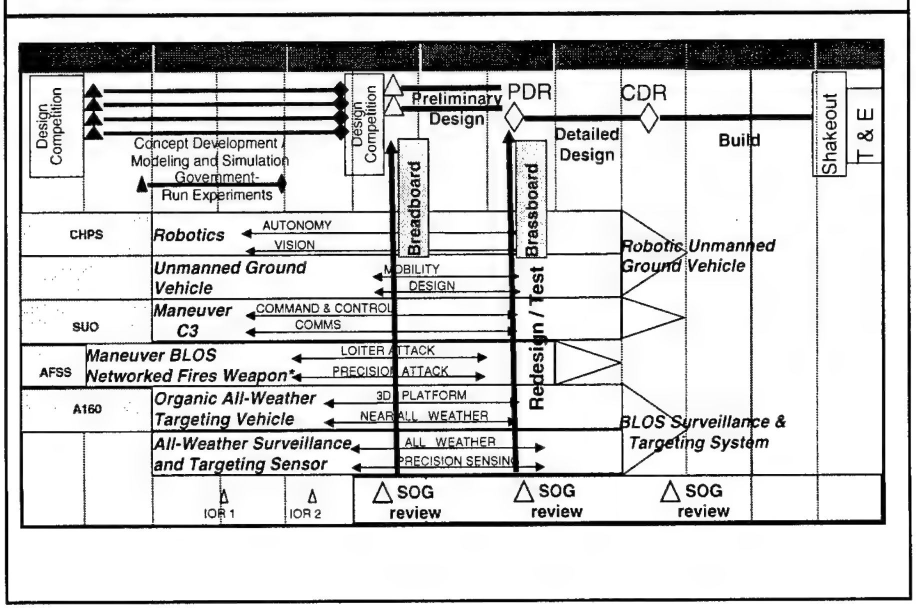


. . . Responsive, Deployable, Agile, Versatile, Lethal, Survivable, Sustainable.

FCS Way Ahead -- "System" FUE FY12

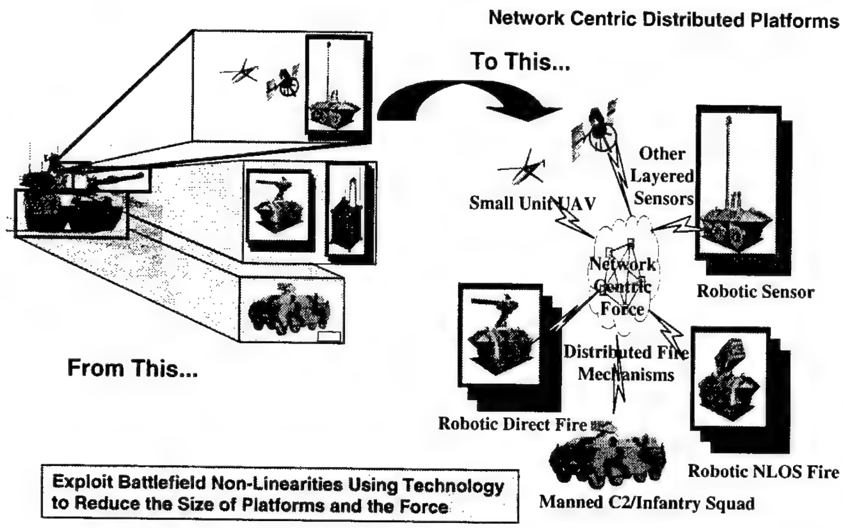


Total Collaborative Effort to Support FCS



FCS Baseline System Concept

Future Combat Systems



Exploit Battlefield Non-Linearities Using Technology to Reduce the Size of Platforms and the Force

FCS Concept Teams

(Six Proposals - Four 845 Agreement Awards)

– The Boeing Team

- The Boeing Company, Seattle, WA
- New Definitions, Inc., Tacoma, WA
- Vector Research, Inc., Ann Arbor, MI
- Whitney, Bradley & Brown, Inc., Vienna, VA
- Signature Research, Inc., Calumet, MI
- National Institute of Standards and Technology (NIST), Gaithersburg, MD
- Rockwell Science Center, Thousand Oaks, CA
- Krauss-Maffei Wegmann (KMW), Germany

– Team Full Spectrum

- SAIC
- United Defense, LP
- ITT Industries
- Northrop Grumman Corp
- Logistics Management Institute (LMI)
- SRI International
- Strategic Perspectives Inc.
- Omnitech Robotics International LLS
- University of Texas Center for Electromechanics
- VRI

– Team Gladiator (Consortium)

- TRW
- Lockheed Martin
- CSC/Nichols Research
- Battelle Institute
- Carnegie Mellon
- IITRI/AB Technologies

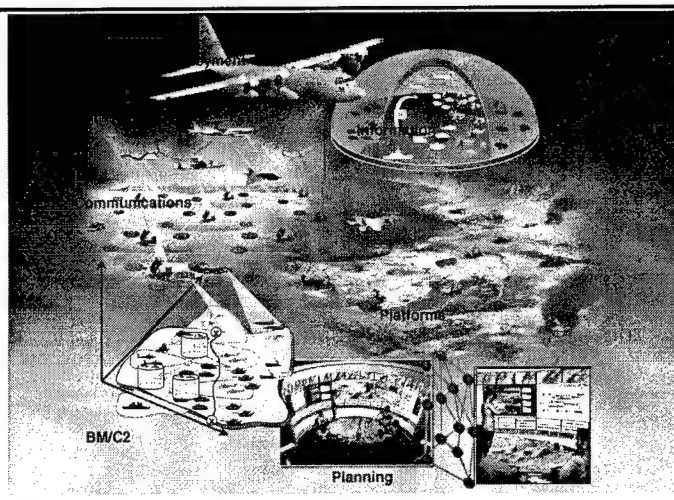
– Team FoCus Vision (Consortium)

- **Team FoCuS vision led by General Dynamics Land Systems Inc., Sterling Heights, Michigan and Raytheon Company, Plano, Texas.**

Other participants with GDLS and Raytheon include:

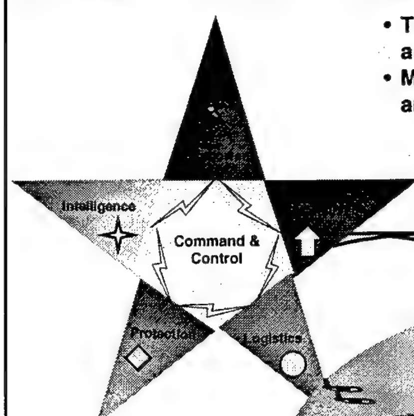
- Aurora Flight Sciences
- Carnegie-Mellon University
- Honeywell
- Maxwell Physics International
- Stanford Research Institute International
- Sensis
- Sensor.com Wireless Integrated Network Sensors
- Whitney Bradley & Brown Inc.
- Los Alamos National Laboratory

Concept - *Boeing Team*

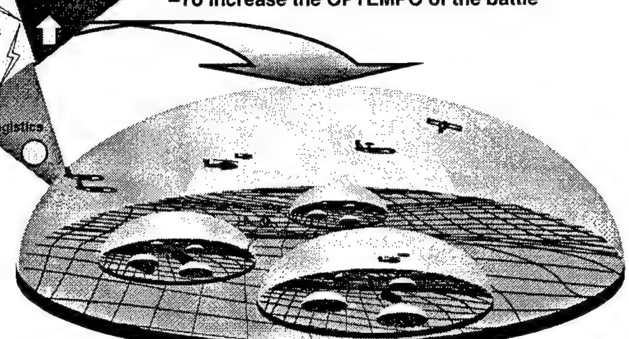


Tailorable multipurpose force comprising an adaptable system of robotic-enhanced platforms brought together by a remoted distributed and non-dedicated architecture.

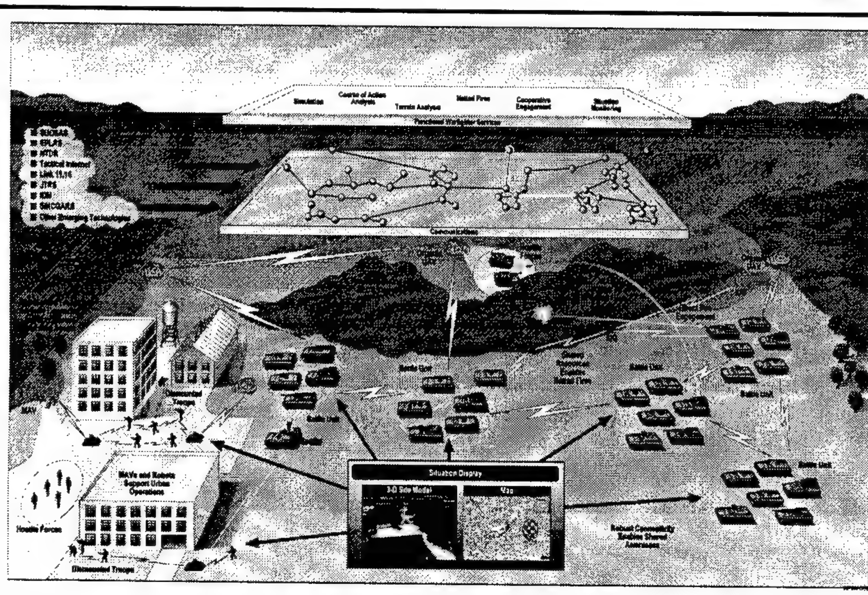
Concept - *Team FoCus Vision*



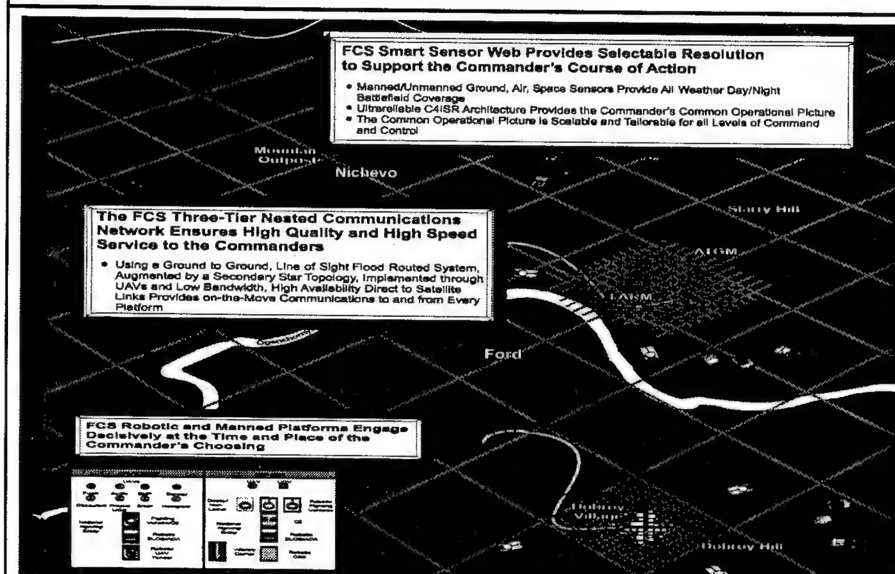
- Transform traditional stovepipe functions into a netcentric system of systems
- Maneuver: through speed, control, protection and deception:
  - To place fires on the enemy
  - To gain positional advantage
  - To increase the OPTEMPO of the battle



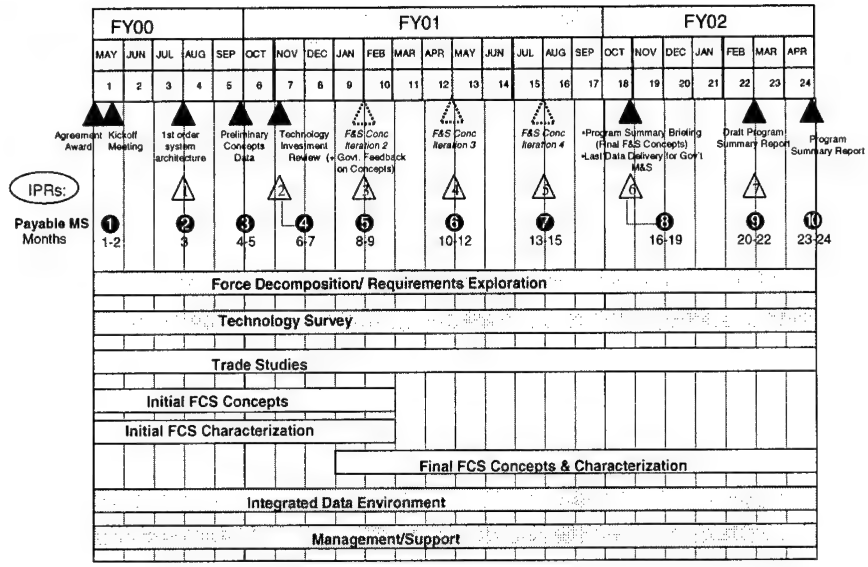
Concept - *Team Full Spectrum*



Concepts - *Team Gladiator*



Milestone/Schedule



Expectations

- Diverse Team backgrounds bring different approaches to defining FCS Force solutions.
- Team taxonomies provide necessary skill and facility mixes to address the needs of the total program.
- Teams, augmented by government expertise and technology, will significantly reduce overall program risk.
- We will understand "what makes a difference" based on government and Team modeling and limited and focused government testing.
- Capability to "reteam" in the next phase will capture the "best of the best."

Summary

- MOA is signed.
- Concept Team Agreements have been awarded and we are underway.
- Program relationships, organizational structure, and significant cost sharing (including Army, DARPA and Industry teams) are in place. PM will transition with program to promote continuity.
- Industry and Government teams are *solid* and enthusiasm levels are high.
- Program is structured to meet 2012 FUE.

Discoverer II
Space Based Radar Concept

DARPATech 2000

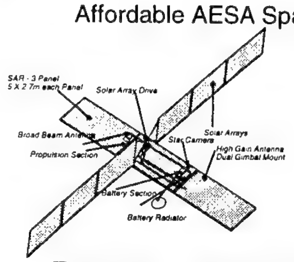
Sept 2000
Allan Steinhardt

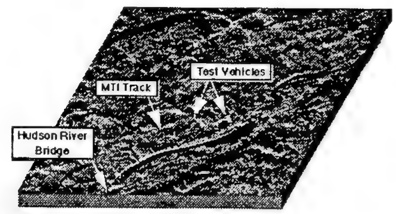
Outline

- The Discoverer II Concept
- New Capabilities
- Active Electronic Scanned Antenna
- Space Based Information Processing
- Mission Utility

Discoverer II Space Radar Objectives

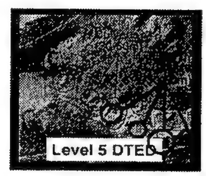
Affordable AESA Spacecraft





MTI Overlaid on SAR Image

- Feasibility of GMTI from space
- Tracking of ground vehicles
- Dynamically tasked imaging of ground targets
- Collection of terrain elevation data
- Show affordability MTI from space



Outline

- The Discoverer II Concept
- → **New Capabilities**
- Electronic Scanned Antenna
- Space Based Information Processing
- Mission UtilitY

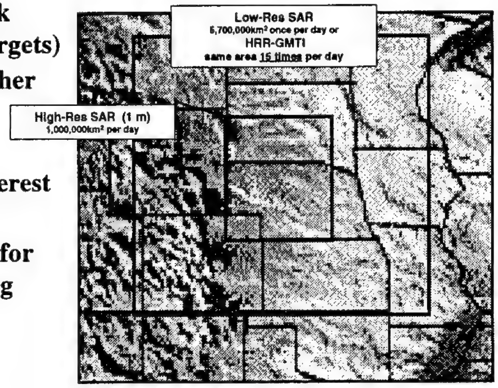
Why Moving Target Indication (MTI)?

- Detect, characterize, and track movers (e.g. critical mobile targets)
- Wide area cueing filter for other modes /ISR assets

Desired Attributes:

- Cover multiple theaters of interest
- "Birth-to-death" tracking
- High range resolution (HRR) for target classification & tracking

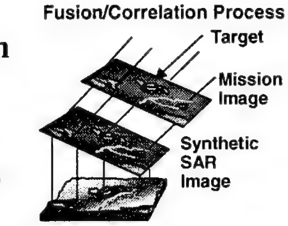
24-Satellite Area Coverage per Day

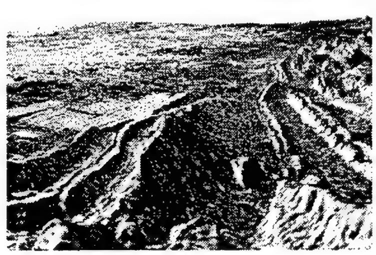


Why Digital Terrain Elevation Data (DTED)?

- Provide common grid for sensor data fusion
  - ➤ Day/night, all weather
- Generate accurate feature location data for targeting and other warfighter applications

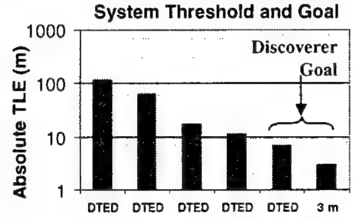
Fusion/Correlation Process





DTED

System Threshold and Goal



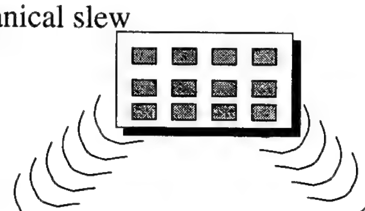
Outline

- The Discoverer II Concept
- New Capabilities
- → $\boxed{\text{Electronic Scanned Antenna}}$
- Space Based Information Processing
- Mission Utility

Affordable Space Based Radar

Active Electronically Scanned Antenna is a key enabler

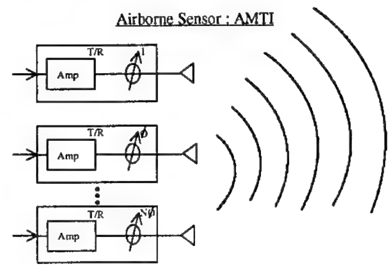
- Change look direction without mechanical slew
  - Simplified satellite bus



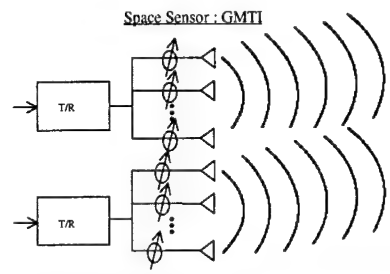
Affordable AESA requires innovation

- Array thinning
  Reduce # modules while retaining scan and beam quality
- Manufacturing
  Heavy automation & streamlined testing
- Adaptive digital radar and signal processing technology
  Relaxed radar tolerances

ESA: Space vs. Airborne



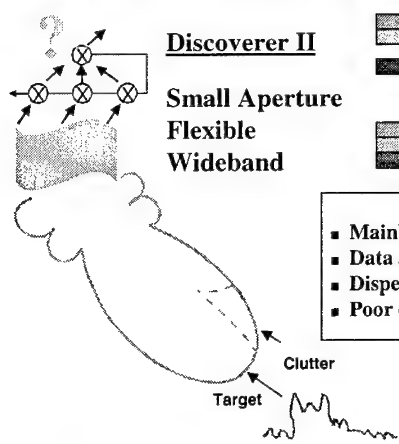
- Technical Challenge: Compactness
- Solution: High power, small aperture
  - 1 element/(T/R)



- Technical Challenge: Power drain, long-range, large field of view
- Solution:
  - Thinned arrays, large aperture, electronic agility

Affordable space AESA leads to large, low-power systems: new challenges

Revolutionary Affordability for Global Surveillance: Satellite Form Factor



Discoverer II

Small Aperture
Flexible
Wideband

- Light, low-cost, multiple satellite/launch
- Increased range resolution enables mainbeam rejection
- Clutter rejection requires Space-Time Adaptive Processing

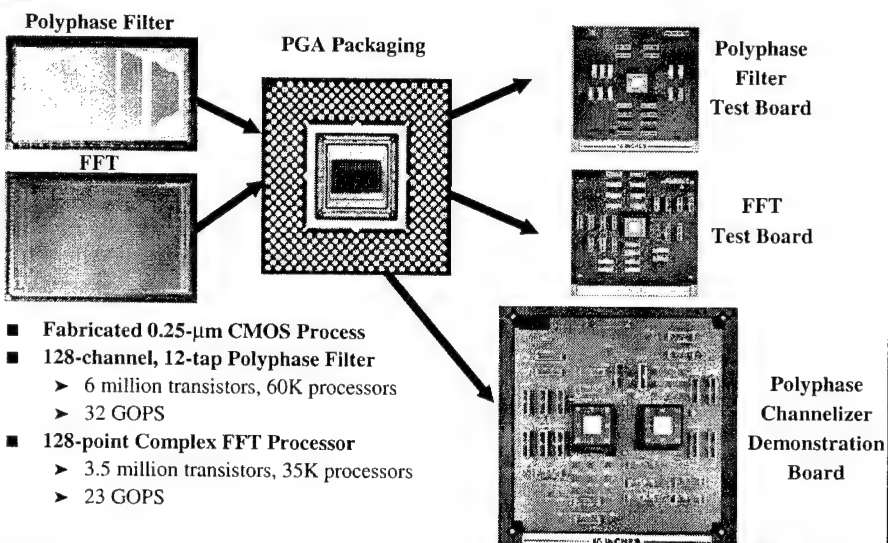
Challenges	Key Enablers
Mainbeam interference	Sub-band architecture
Data adaptive calibration	Teraflop-class processing
Dispersion mitigation	Wideband communications
Poor cross-range resolution	HRR MHT tracker

Emerging information technologies enable affordable constellation

Outline

- The Discoverer II Concept
- New Capabilities
- Electronic Scanned Antenna
- → **Space Based Information Processing**
- Mission Utility

Wideband Digital Processing Enables Relaxed Antenna Specifications

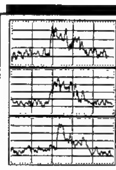


- Fabricated 0.25-μm CMOS Process
- 128-channel, 12-tap Polyphase Filter
  - 6 million transistors, 60K processors
  - 32 GOPS
- 128-point Complex FFT Processor
  - 3.5 million transistors, 35K processors
  - 23 GOPS

Discoverer II Signal Processing Flow: Tracker

Detector → Target Reports → Tracker → Tracks

Target Reports



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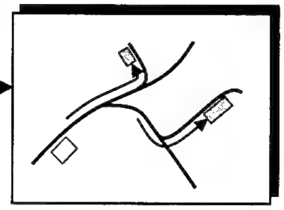
Tracker

HRR-MHT

- Poor cross range
  - → Tree pruning
  - → Bootstrap ATR
  - → Road-aided track
  - → DTED obscuration, geolocation
- High PFA
  - → SAR clutter edit
  - → Range profile edit
  - → Power selected training
- Cross-platform fusion
  - → Angle-diverse ATR
  - → Road, DFAD alignment

Tracks



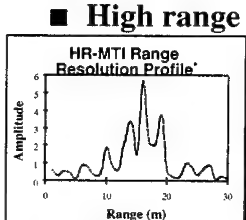
Clutter
Receiver Noise
Targets

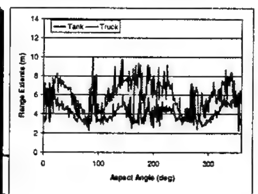
Tracker compensates for platform stand-off/diversity

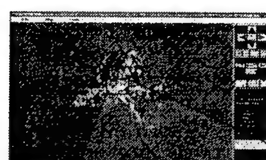
DARPA

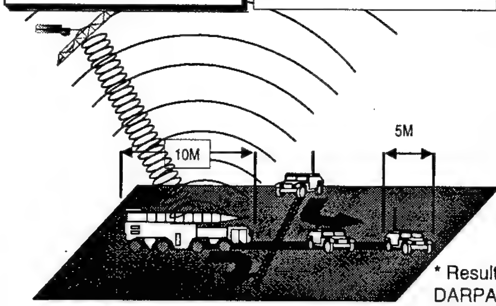
Feature-aided Tracking

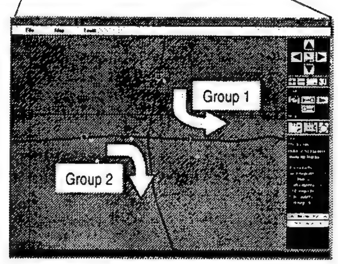
- High range resolution allows target deconfliction











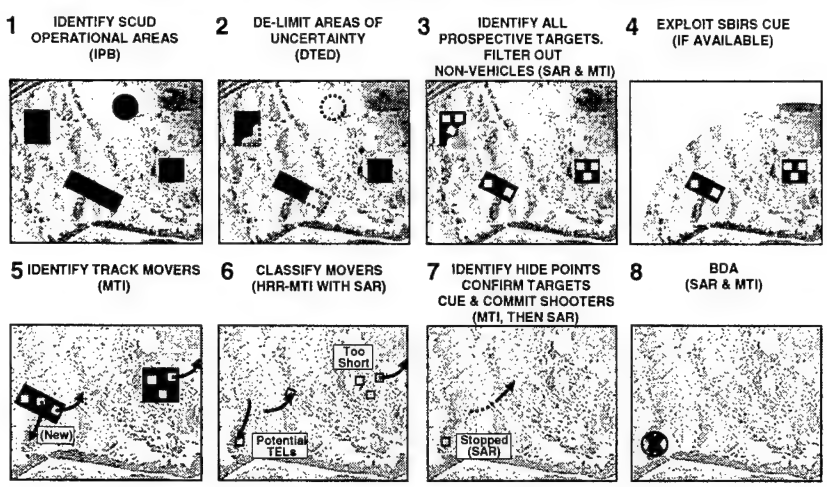
* Results derived from MSTARS collections, DARPA MTE Program, 11/97

DARPA

Outline

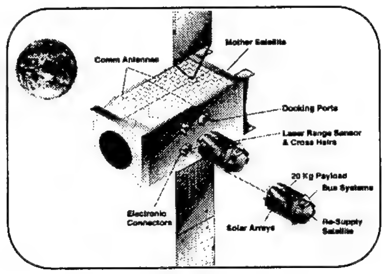
- The Discoverer II Concept
- New Capabilities
- Electronic Scanned Antenna
- Space Based Information Processing
- → **Mission Utility**

Prospective Strategic Relocatable Targets/Critical Mobile Targets Applications



ORBITAL EXPRESS

A Comprehensive Architecture for the 21st Century



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DoD Space Architecture Limits

TTO

☆ Operational

- ⇨ **System availability concerns force risk intolerance**
- ⇨ **Predictable orbits allow scheduling by adversaries**
- ⇨ **Orbital infrastructure does not account for vulnerability**
- ⇨ **Limited ability to tactically optimize orbital configuration**
- ⇨ **Finite fuel restricts utility**

☆ Costs

- ⇨ **Complex, highly redundant, cross-strapped designs**
- ⇨ **Manned servicing is cost prohibitive —$2M+ /orbital-hr**
- ⇨ **High fuel fraction costs for "maneuverable" satellites**

☆ Technology

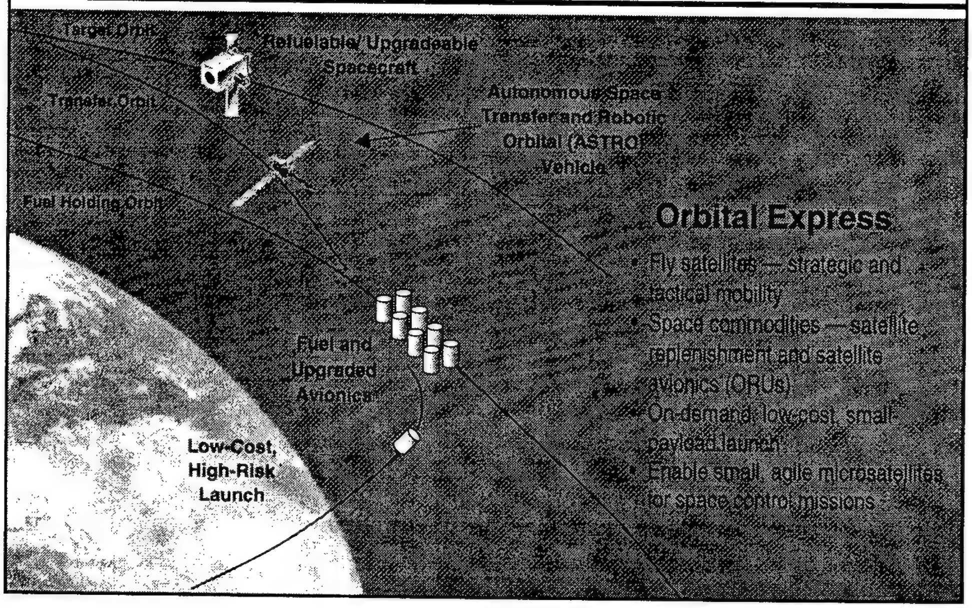
- ⇨ **On-orbit technology at least 10-15 years old**
- ⇨ **Unmanned satellite servicing requires development**

DARPA

2010 Space Architecture

- The Long View-

TTO



DARPA

Orbital Express
Military & Intelligence Advantage

TTO

- ☆ **Enable new and enhanced capabilities**
  - ➪ **Adjustable satellite coverage / optimization**
    - Optimize "thin" constellations to provide regional focus (greater coverage)
    - Operate at different altitudes as needed
    - Formation "flying"
  - ➪ **Random ΔV: Counter adversary activity scheduling (D+D)**
  - ➪ **Enable space control options**
    - Protection: evasive and unpredictable maneuvers
    - Situational awareness: highly agile surveillance system
  - ➪ **Leverage long-lived hardware — reduce cost, increase capability**
    - Extend lifetimes
- ☆ **Enable a revolution in space affairs**
  - ➪ **Extensible design + space commodities**
    - ⇒ ***Commercial competitive advantage for US industry***

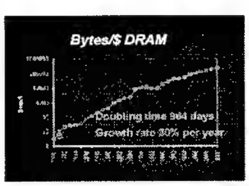
History of On-Orbit Servicing

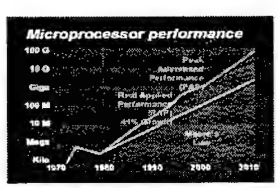
- ☆ 1999 (MIT/LL, JPL, NRL, Draper): Substantial cost saving + significant operational utility
- ☆ 1999 (Leisman & Wallen): Up to $2B savings for upgrading GPS constellation vs. replacement
- ☆ 1998 (NRL): 28% cost savings + greatly increased sensor availability attributable to spacecraft modular architecture design
- ☆ 1987-1989 (SDIO / BMDO): 9% - 50% savings with on-orbit support
- ☆ 1979 (Classified): "Significant" cost savings to a specific constellation attributable to on-orbit refueling
- ☆ 1974 (TRW): 22% savings due to in-space servicing of DSP satellites

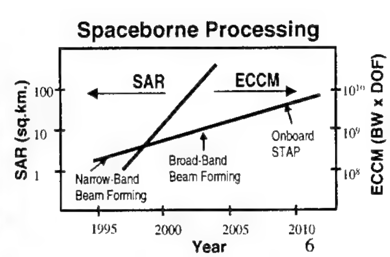
Numerous studies have shown refueling / upgrading produces significant life-cycle cost savings

P3I Satellite Architectures Extend "Moore's Law" To Space

- ☆ Accommodate differing rates of technology advance
  - ⇨ Orbital Replacement Units (ORU) to improve system performance over time
  - ⇨ "Plug-and-Play" architectures can be made highly adaptable
  - ⇨ Exploit long-lived components (bus, sensors, solar panels)
- ☆ Enable new capabilities
  - ⇨ "Tightly coupled" systems—cross cueing/ tasking of new systems
  - ⇨ Adapt to counter-measure threats
- ☆ Less initial risk reduction required on upgradable avionics
- ☆ Reduction in satellite systems' cost







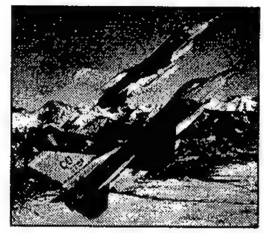
Planned System Upgrade Standard Procedure for Aircraft

☆**F-16 Multinational Staged Improvement Program (MSIP)**

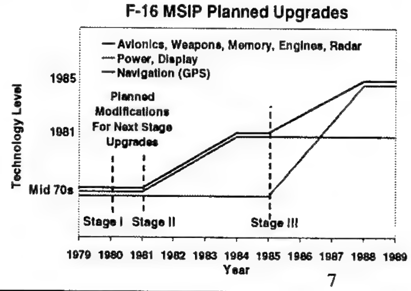
- ➩ **Plan progressive upgrades**
  - ✈ Airframe life is long - technology evolving slowly
  - ✈ Avionics technology progressing quickly - short obsolescence cycle
- ➩ **Retrofit upgrades to earlier F-16s**
  - ✈ Early airframes configured to accept future upgrades
- ➩ **Upgrade**
  - ✈ Processing speed, bandwidth and memory
  - ✈ Defense capability, displays, weapons and warning systems
  - ✈ Communications and navigation (GPS)

☆**Advantages**

- ➩ **Increase service life and capability**
- ➩ **Reduce cost and time to retrofit**

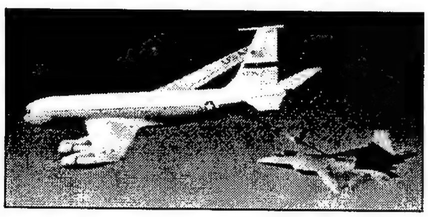


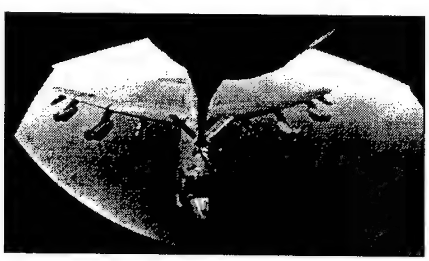
F-16 MSIP Planned Upgrades



7

In-Flight Refueling - A Revolution in Military Aircraft Capabilities



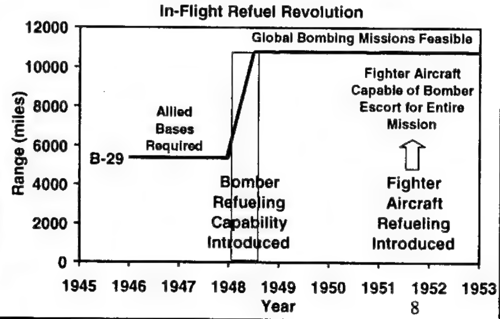


☆ **Revolutionize aircraft missions**

- ➩ **Extend range and duration**
  - ✈ Global missions feasible
  - ✈ Fighter escorts sustainable

☆ **Reduce cost and time compared to base refueling**

In-Flight Refuel Revolution



8

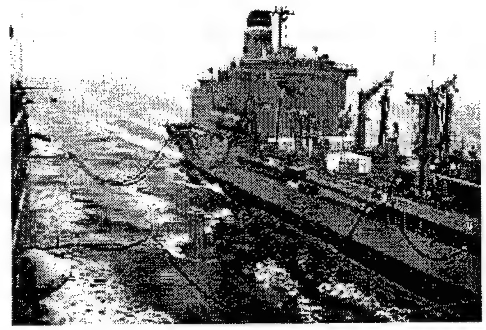
New Capability In Space: "Orbital Replenishment"

Navy's underway replenishment (UNREP) capability provides:

- ⇨ Force multiplier
- ⇨ Flexibility
- ⇨ Enhanced on-station time
- ⇨ All commodities for extended operations: food, fuel, ammo, repair parts
- ⇨ About 1 shuttle craft (fast replenishment ship) per 10 combatants (CVBG)

Man-in-loop required for:

- ⇨ Station keeping
- ⇨ Dexterous manipulation
- ⇨ Anomaly detection / crisis resolution



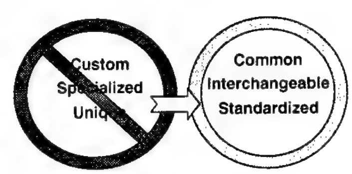
ORBREP versus UNREP:

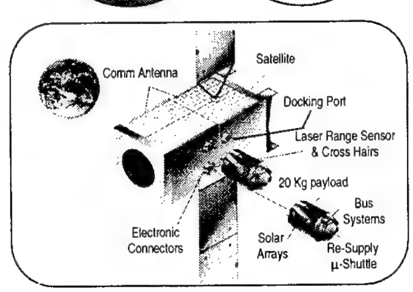
- ⇨ Same force multiplier and flexibility benefits
- ⇨ Man-in-loop required only for anomaly detection / crisis resolution
- ⇨ Nominally one servicing spacecraft per orbital plane

9

New Refuelable & Upgradable Satellite Design/Architecture

- ☆ **Design, Build, Add an Extensible Satellite**
- ☆ **Preplanned Product Improvement (P³I) Satellite Design**
  - ⇨ **Standards Based "Dockable" Interfaces**
    - ✈ Thermal
    - ✈ Signal
    - ✈ Power
    - ✈ Inertial
  - ⇨ **"Plug and stay" ORUs for Avionics P3I**
    - ✈ Electronics
    - ✈ Power systems
    - ✈ Stabilization
    - ✈ RF elements
  - ⇨ **Extensible Avionics**
  - ⇨ **Refuel Spacecraft Features**
  - ⇨ **Expendables Replenishment**
    - ✈ Fuel, batteries, cryogens

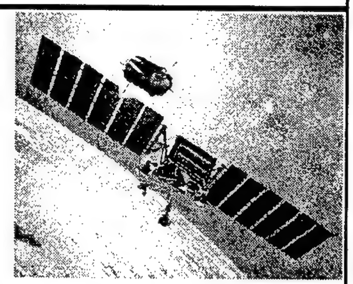


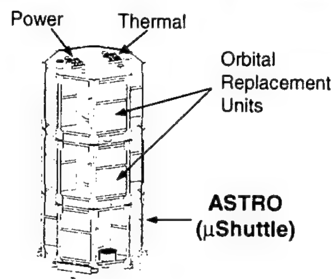


10

ASTRO Servicer
Autonomous Space Transporter and Robotic Orbiter

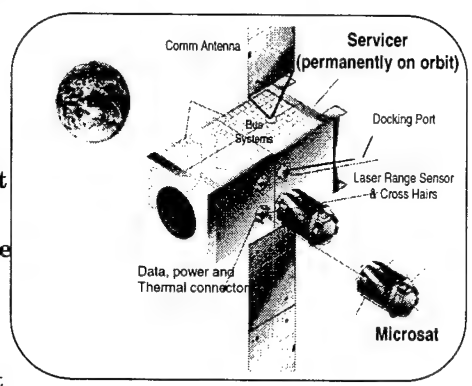
- ☆ **Design, Build, and Demo a Servicer for In situ Refueling and Modular Upgrade**
- ☆ **Servicer Functions:**
  - ⇨ **Avionics/fuel canister capture, transport**
  - ⇨ **Autonomous satellite rendezvous & docking**
  - ⇨ **Fuel/Orbital Replacement Unit delivery**
  - ⇨ **Inspection**
  - ⇨ **Host platform for MicroSatellites**
- ☆ **Technical Challenges & Opportunities:**
  - ⇨ **Autonomous rendezvous/precision docking**
  - ⇨ **Soft capture mechanism**
  - ⇨ **Electrical/photonic/thermal interfaces**
  - ⇨ **Propulsion & attitude systems**





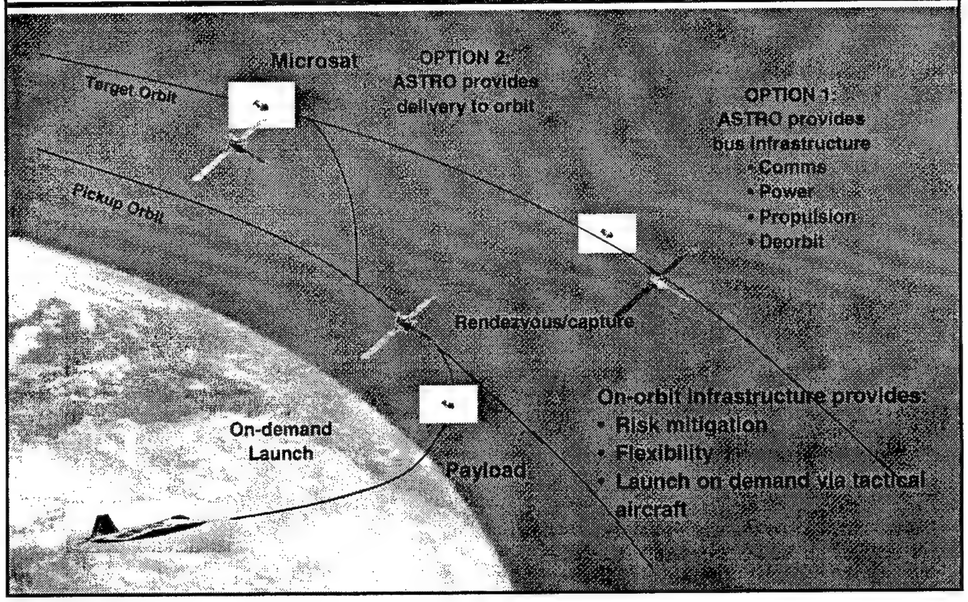
Enabling a Robust MicroSatellite Capability/Architecture

- ☆ **A space logistics vehicle (e.g. the Orbital Express ASTRO vehicle) can provide bus functions to MicroSatellites**
  - ⇨ **Maneuverability / orbit raising**
  - ⇨ **Power**
  - ⇨ **Communications**
  - ⇨ **Attitude control**
- ☆ **Risk is mitigated by using proven on-orbit bus systems**
- ☆ **More MicroSatellite mass can therefore be devoted to payload**
- ☆ **Use of low-cost, on-demand launch opportunities (F-15 /F-22, secondary payload) for delivering MicroSats to orbit now becomes feasible**



Orbital Express Enables

Robust MicroSatellite Architecture



Why MicroSatellites?

☆ **Lower weight ↔ lower launch costs**

☆ **Leverage excess capacity on large vehicles through secondary payload capability**

☆ **Expand number of organizations manufacturing spacecraft**

☆ **Cluster operations ↔ graceful degradation, distributed functionality**

☆ **Low observability**

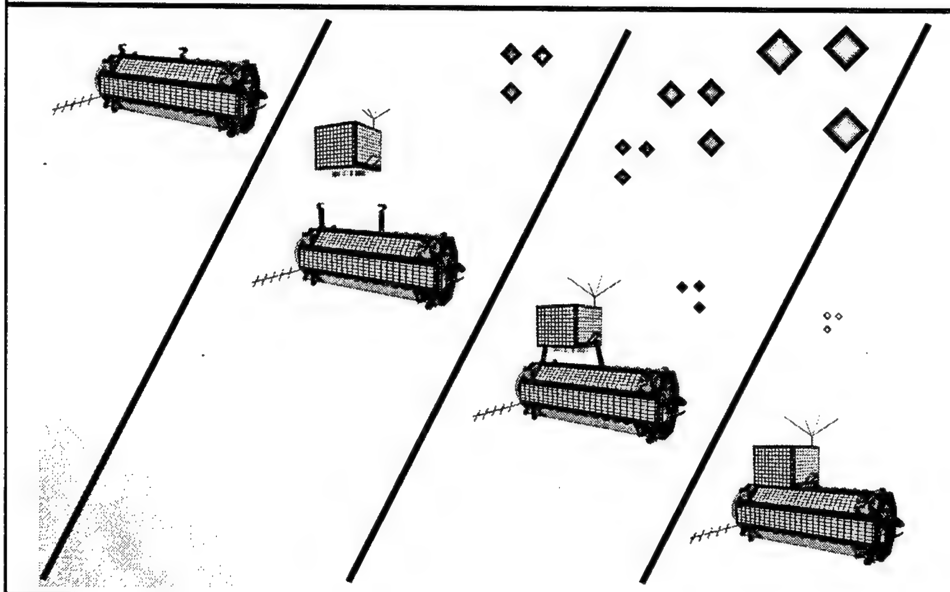
What Limits Useful Missions for MicroSatellites?

☆ **Mass drivers in satellite design**

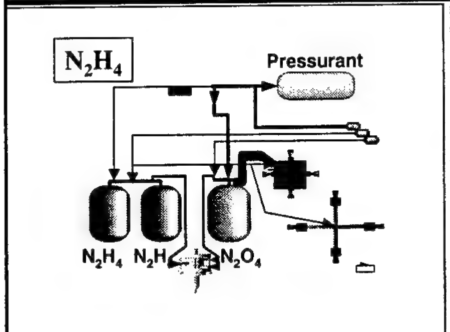
- ⇨ **Structure:** Must withstand launch acceleration and vibration loads
- ⇨ **Solar panels:** Must be deployable if mission requires high electrical power (e.g., comms)
- ⇨ **Batteries:** Required for operability / sustainment during eclipse (almost 50% of time for LEO spacecraft)
- ⇨ **Optics:** Massive primary elements required to obtain adequate resolution
- ⇨ **Radar:** Array, transmitter, power storage & handling are large for adequate resolution
- ⇨ **Propulsion:** Thrusters and fuel (maneuverability, orbit maintenance, deorbit)

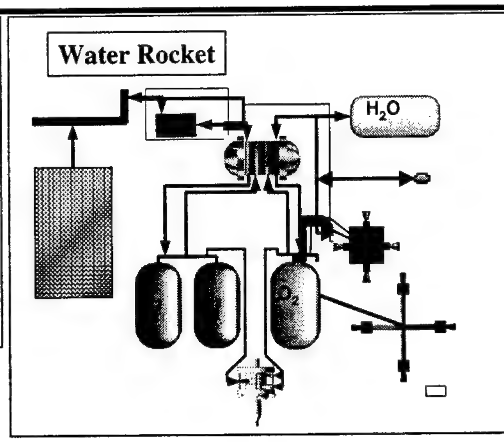
The weight required for bus functions can limit payload weight and capability.

ASTRO MicroSat Docking



What is the Right Fuel Infrastructure?



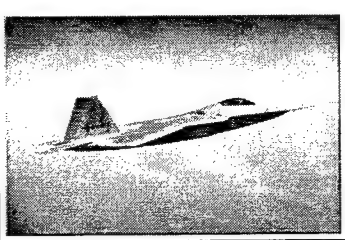


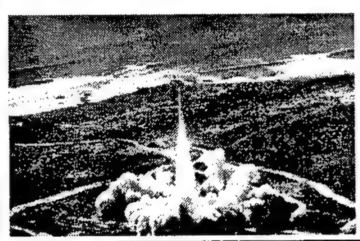
☆ **Fuel attributes**

- ⇨ High Isp
- ⇨ Long-term on-orbit storage
- ⇨ Relatively non-hazardous at launch
- ⇨ Multi-mode
- ⇨ Multiple resupply options

Delivering Material To Space

Launch Option	*Average Cost*
Dedicated	\$ 5,000 - 10,000 / lbW
Piggy Back/Adapter Rings	\$ 1,000 - 2,000 / lb
High Tempo - High Risk/Low Cost	\$?
Gun Launch from Earth	\$?
Aircraft Launch	\$?





Summary

- ☆A comprehensive on-orbit servicing architecture enables:
  - ⇨Ready availability of fuel, providing the tactical agility required for a wide range of current and emerging missions
  - ⇨Modular replacement function leading to multi-mission capability and life extension
  - ⇨Bus functions and orbit transfer service for MicroSatellite operations
  - ⇨Reduced mission risk through proven on-orbit infrastructure
- ☆All of these provide opportunities for new and enhanced military applications
- ☆Life cycle cost reductions will come when infrastructure is in place

Dynamic Database

Efficiently convert massive quantities of sensor data into actionable information for tactical commanders

Mr. Otto Kessler

Program Manager

Tactical Technology Office
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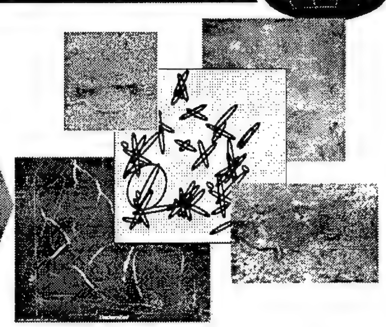
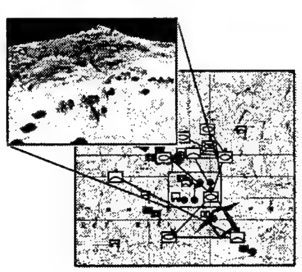
Motivation

- ***What the Commanders get . . .***
  - Large numbers of partially overlapping sensors
  - 100s of reports; 1000s of images per minute
  - Unregistered, soda straw sensor observations
  - Very high false alarm rates
  - Signals - based

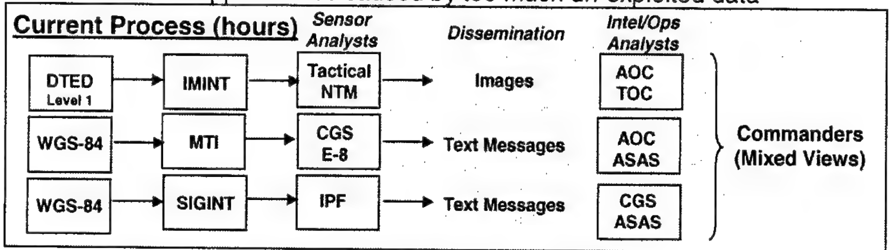




- ***What the commanders want . . .***
  - Timely situation knowledge
  - Comprehensive coverage (>1000 targets over ~1000 Km^2)
  - Accurate target locations with small Circular Error Probabilities
  - Low burden, geo-referenced database

The Problem

- Sensor data increasing exponentially
  - FIA, Global Hawk, etc.
- Single source analysts decreasing at high rate
  - No multi-sensor analysts
- Targeting decision cycle delayed by manual processing
- Missed opportunities caused by too much un-exploited data

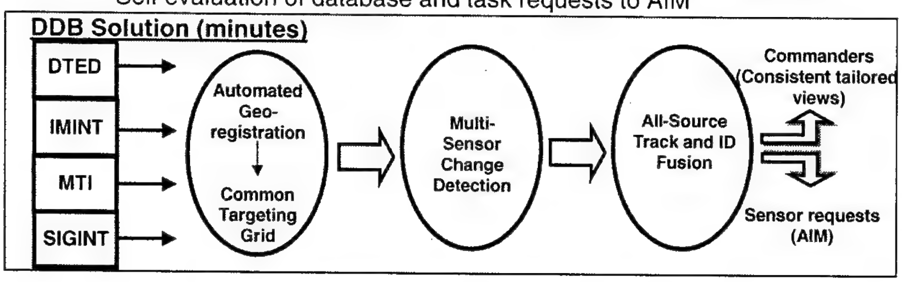


- Example - Image centric surveillance - Kosovo
  - Pixel by pixel "eyeball change detection"
  - Single sensor at a time("stovepipe analysis")
  - Manual exploitation - hours to days for product
  - No automatic multi-sensor geo-registration

Consequence: *Failure to find / identify targets*

DDB Solution

- **Common geo-registered database**
  - Common grid tied to wide area terrain data (DTED, CIB, FFD)
  - Multi-sensor observations (SAR, EO, IR, GMTI and SIGINT)
- **Fusion across sensors**
  - Model based evidence accumulation
- **Track targets and features at object level**
  - Wide area coverage, large numbers of targets
- **Dynamic closed loop tasking overcomes missing/ambiguous data**
  - Self evaluation of database and task requests to AIM



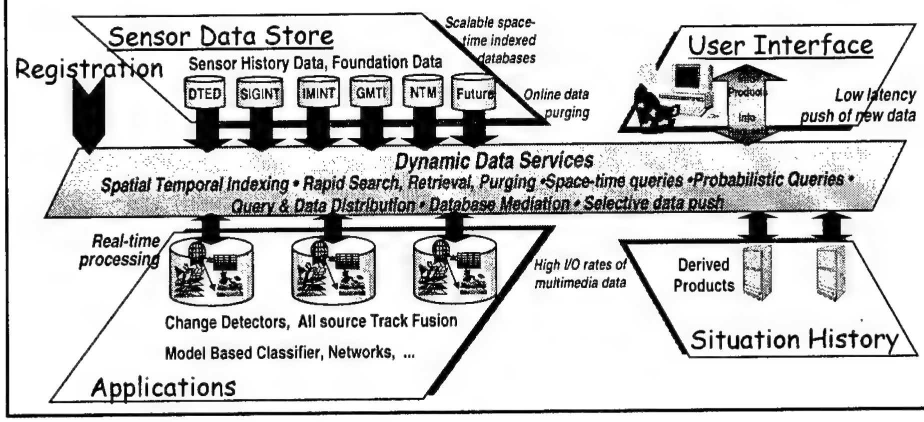
Dynamic Multi-sensor ISR Database

DDB Architecture

Enables Sensor Data Access and Technology Growth

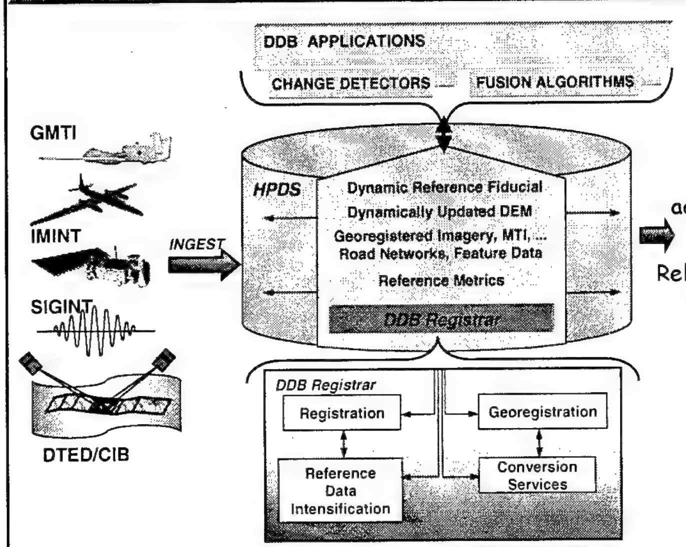
DARPA

- Database architecture overcomes limitations of data ownership
- Enhances:
  - Data sharing, interoperability
  - Technological growth - applications and visualization
- Leverages COTS thrusts in "open systems" & "object oriented databases"
  - Explore military needs which exceed likely commercial interests



Registration of all Sensors to a Common Targeting Grid

DARPA

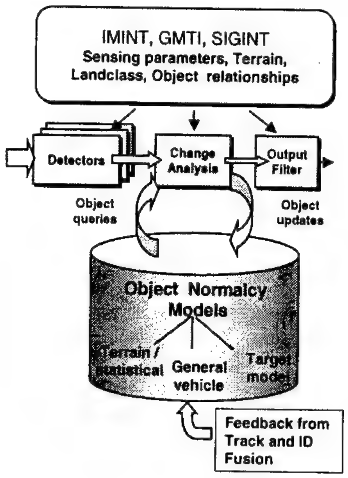


Absolute geospatial accuracy for targeting (~10 m.)

Relative georegistration for change detection (<1m.)

Dynamic update of reference data

Normalcy Models Enable Wide Area Change Detection



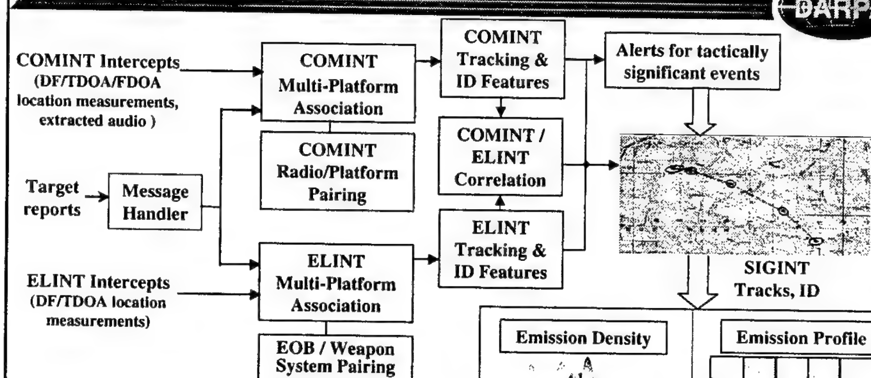
Normalcy models provide context for detection thresholds

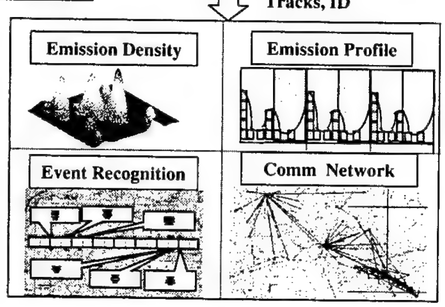
- Is this a region of high clutter?
- Was it there on the last sensing pass?
- Has it changed state or shape?
- Is it emitting as expected?
- Is it moving in a new way, place, or time?

Combined multi-sensor data is required to derive normalcy

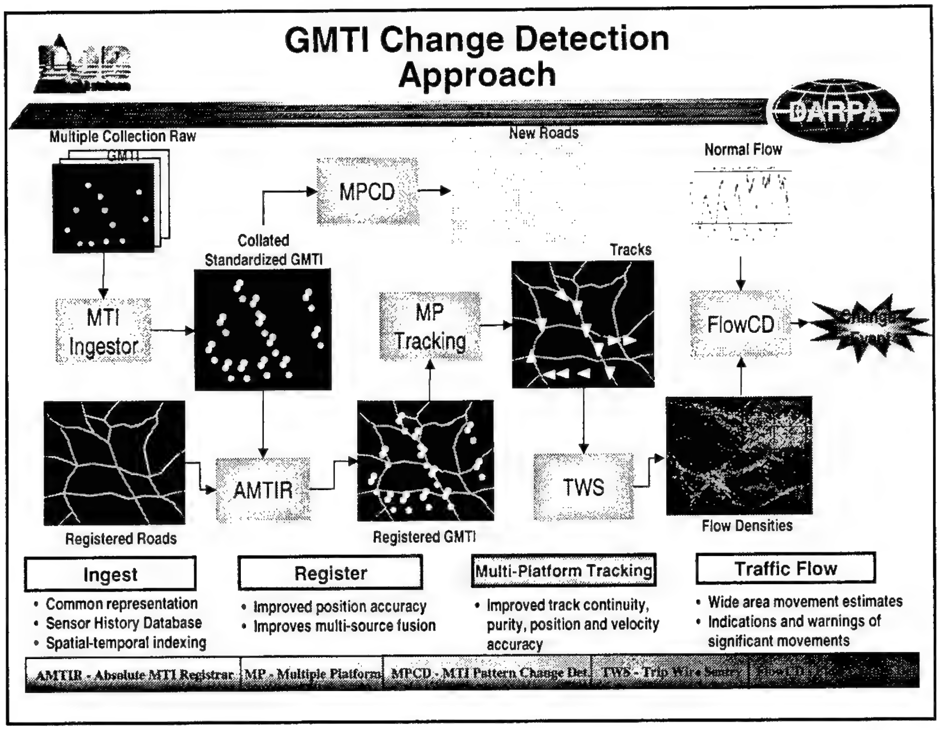
- Spatial, temporal, feature based representation of scene content, background, and behavior.

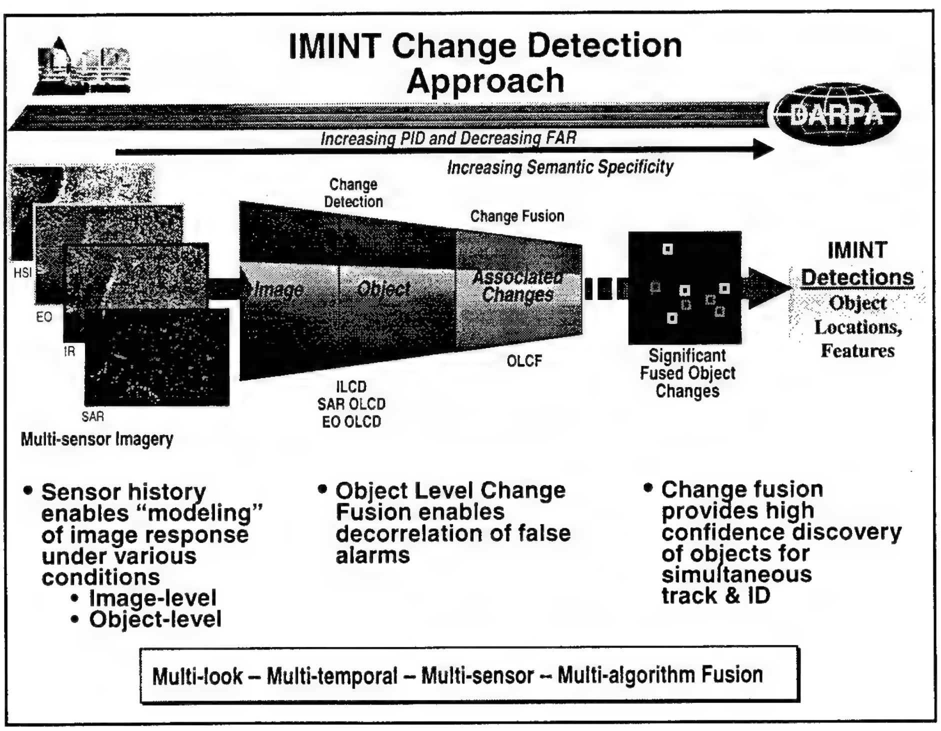
SIGINT Change Detection Approach





- Analysis of spatio-temporal structure of RF activity:
  - **Emission Density** - Exploits spatial features of the battlefield
  - **Emission Profile** - Exploits periodic activity of the battle space
  - **Communication Network** - Maps lines of communication between entities and echelon levels

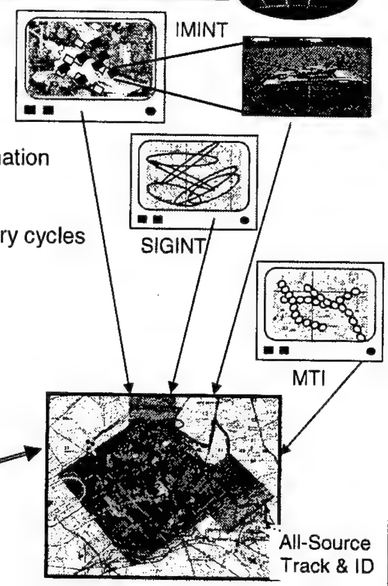

GMTI Change Detection Approach
DARPA
Multiple Collection Raw GMTI
New Roads
Normal Flow
MPCD
Collated Standardized GMTI
Tracks
MTI Ingestor
MP Tracking
FlowCD
Change Event
AMTIR
TWS
Registered Roads
Registered GMTI
Flow Densities
Ingest
• Common representation
• Sensor History Database
• Spatial-temporal indexing
Register
• Improved position accuracy
• Improves multi-source fusion
Multi-Platform Tracking
• Improved track continuity, purity, position and velocity accuracy
Traffic Flow
• Wide area movement estimates
• Indications and warnings of significant movements
AMTIR - Absolute MTI Registrar
MP - Multiple Platform
MPCD - MTI Pattern Change Det.
TWS - Trip Wire Sentry
FlowCD

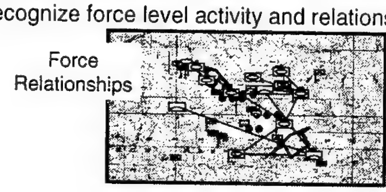

IMINT Change Detection Approach
DARPA
Increasing PID and Decreasing FAR
Increasing Semantic Specificity
HSI
EO
IR
SAR
Multi-sensor Imagery
Change Detection
Change Fusion
Image
Object
Associated Changes
ILCD
SAR OLCD
EO OLCD
OLCF
Significant Fused Object Changes
IMINT Detections
Object Locations, Features
• Sensor history enables "modeling" of image response under various conditions
• Image-level
• Object-level
• Object Level Change Fusion enables decorrelation of false alarms
• Change fusion provides high confidence discovery of objects for simultaneous track & ID
Multi-look – Multi-temporal – Multi-sensor – Multi-algorithm Fusion

All-Source Track & ID Fusion Approach

DARPA

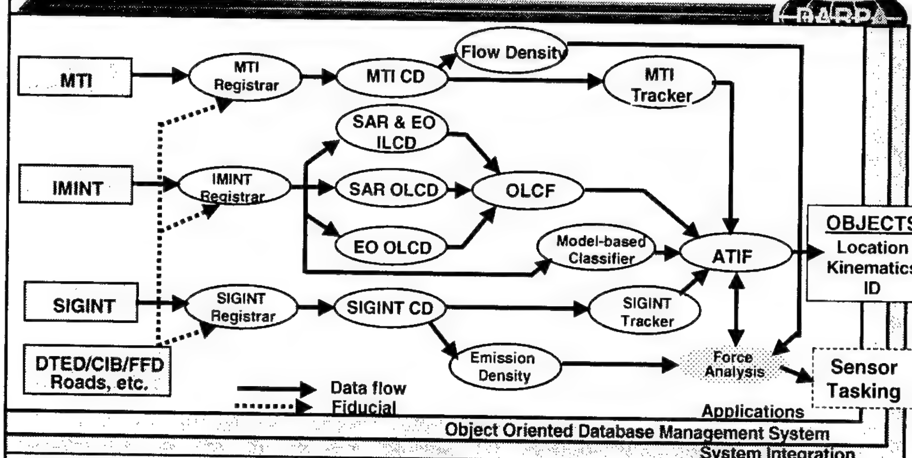
- **Fuses Change Detector Outputs**
  - Detections, tracks, identifications, features
  - MHT (Multiple Hypothesis Tracker)
  - Support sensor tasking
- **Target Identification**
  - Fuse and maintain SIGINT/ IMINT identity information
  - Model based classifier
    - EO and SAR classification of vehicles
  - SIGINT ID features link with moving and stationary cycles
- **Target Track Continuity Through Move-stop-move Cycles**
  - Fuse GMTI and SIGINT when moving
  - Fuse IMINT and SIGINT when stopped
  - Increase track length relative to MTI alone
  - Recognize force level activity and relationships





DDB Algorithm Relationship

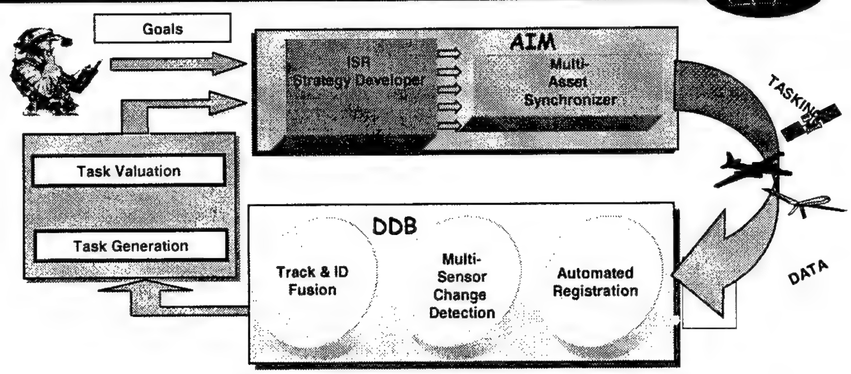
DARPA



- **Registration:**
  - Shared multi-spectral fiducial
  - Salient feature matching
  - Iterative refinement
- **Change Detection:**
  - Adaptive background modeling (normalcy)
  - Spatial and temporal pattern analysis
  - Tripwires
- **All-Source Track & ID:**
  - Correlates detection features from sensors
  - Accumulate over time
  - Maintain through move/stop/move cycles

ILCD: Image Level Change Detection ◆ OLCD: Object Level Change Detection ◆ OLCF: Object Level Change Fusion ◆ ATIF: All-Source Track & ID Fusion

Data Driven Collection Management

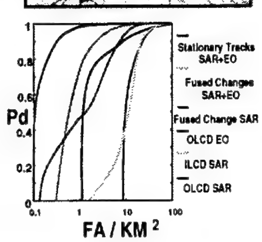


- **Goal: Close the Loop Between Collection Management and Situation Estimation**
  - Now: Manual coupling
    - Forces tasking focus to be on static targets
    - Limits use of uncertainty info in task valuation
  - Future: Automate process by developing
    - Task generation from ambiguities in fused product
    - Task valuation based on uncertainty estimate of the current situation

DDB Accomplishments

Demonstrated Benefit of Fusion Gain

- Wide Area Change Detection (WACD)
  - IMINT
    - Statistical normalcy models to recognize change and reject false alarms
    - EO/SAR fusion reduced FAR ~4x in experiments
  - MTI
    - Increased track continuity by 27%
    - Reduced error in position by 37%
  - SIGINT
    - New emitter mapping and profiling capability
    - 50% reduction in emitter location error through multi-platform fusion
- All-source track and ID Fusion (ATIF)
  - Developed new capability to maintain track through *move - stop - move* cycles
  - Association of mover/sitter tracks extends track continuity ~x4
- Dynamic Data Services
  - Common targeting grid
  - Registered sensor histories over space and time



Foundation technologies to produce a timely, accurate estimate of the ground situation (kinematics, locations and IDs of objects)

Information Technology Office Overview

Dr. Shankar Sastry, Director
Information Technology Office
Defense Advanced Research Projects Agency

DARPA Has Done Great Things for IT

Mission of ITO: Superiority of Armed Forces Through Revolutionary Advances in:

- High Performance Computing and Communications Devices
- Networking and Information Assurance
- Embedded Software
- Seamless User Interfaces for the War Fighter
- Ubiquitous Computing and Communication Resources

The investment by DARPA in Information Technology development has been the primary factor in the creation of an information based economy whose current annual volume is about $500 B *per year* in the US alone. This number is to be compared with other sectors of the economy such as communications $1 trillion, transportation $750 B, and health care $2.5 trillion.

That's great: what remains to be done? Where do we go from here?

Drivers of IT Research

Computing, Networking, Security have come a long way, but they have a long way to go.

Key drivers:

- wireless and power aware computing devices,
- ubiquitous computing devices,
- embedded computers, (interacting in real time with sensors and actuators),
- wideband optical networks,
- MEMS,
- quantum devices,
- system on a chip: billion transistor chip, photonic interconnects, programmable hardware,
- cognitive neurophysiology,
- bio-informatics.

What Are the Hard Problems??

Wireless:

1. Power/ Energy Aware Computing and Communication (PAC/C): design suites for trading off power/energy consumption. Design environments for integrated design across algorithms, instruction sets, and device clock/frequency characteristics.
2. Distributed Computation with sensors which have to trade off on board computation with communication. Thresholding phenomena in performance improvement of networked sensing systems. (SensIT)
3. Secure Ad-hoc networking protocols for insecure and jammable networks. Game theoretical approaches to information assurance in a hostile environment, physical layer and network layer.

What Are the Hard Problems??

Ubiquitous Computing Devices:

1. Hands off interaction with portable or omnipresent computers. Need for voice / speech / foreign language recognition. (Communicator, TIDES)
2. Operating Systems for small sensors, embedded devices for specialized operation. (Ubiquitous Computing)
3. Ad-hoc networking, content addressable data, queries for intermittently available data stores. (Ubiquitous Computing)
4. Dynamic caching of data, data provisioning systems, aggregation of temporally evolving data. (IM, Ubiquitous Computing)
5. Collaborative and Hierarchical Decision Making Environments. (Ubiquitous Computing)

Hard Problems Continued

Optical Networking

- WDM is nearing maturity, however optical networking protocols for WDM over IP are not ready yet: routing, congestion control, network management. (NGI)
- Security of high speed networks.
- Modeling, estimation and control of traffic at various levels of granularity on WDM networks, ATM networks, WAN and Ad-hoc Wireless Networks is in its infancy. QoS for different streams of traffic. (NMS)

MEMS

- Smart matter: the integration of MEMS actuators and sensors with computation and networks. (seedling, amorphous computation)
- SmartDust: usage of MEMS sensors with wireless, GPS, biochemical sensors and ad-hoc networking to enable distributed detection and tracking of bio-hazards (SensIT)
- Computational infrastructure for distributed, Networked Embedded Systems.

Hard Problems Continued

Computational Models "Beyond Si"

- New paradigms for secure communication and computation.
- Quantum, DNA, smart matter models of computation: Amorphous Computing. Challenge problems: quantum and string theoretic simulations of molecules.
- Integrate adaptively computational elements ASICs, FPGAs, programmable elements using optical interconnects to incorporate security into computational fabric.
- Programmable hardware with verified components for morphing computational elements and power aware applications. (Just-in-Time, DIS)

Hard Problems Continued

Cognitive Neurophysiology:

- Interfacing computer memory to human memory, models of memory and forgetfulness to augment situation awareness. (ISAT Study Area)
- Learning of information search patterns and language acquisition. (TIDES)
- Synthesis of speech, gaze, gesture, and lip reading for noisy, multi-speaker environments.

Computational Biology:

- Hidden Markov models for biological models of gene expression and phenotype expression. Putting biological content into phenomenological models, bio-informatics.
- Architectures for computation, hardware and software with the fault-tolerant and self-organizational character of biological systems.
- Modeling and Control of genetic circuits for applications like suppression of piliation or forced sporulation, multi-grained models of the organism, cell, DNA, gene computational elements.

Hard Problems Continued

Embedded Computers and Software:

- Distributed software each performing time critical tasks needed to coordinate with guarantees of overall QoS. (Quorum)
- Verified software for adaptable, time critical operations with multiple distributed processes for physical systems whose mode changes depending on mission priorities. (SEC)
- Model based design of embedded software for hardware-software codesign. The goal is to have embedded software keep up with Moore's law advances in processor speed. (MoBIES)
- Networked Embedded Systems compositionality and distribution of the subsystems is unknown resulting in large cost overruns and worse inadequate performance in real-time embedded software for distributed sensing and control.

Current ITO Programs

Intelligent Software

- Communicator
- Information Management
- Translingual (TIDES)

Autonomous and Embedded Systems

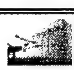
- Autonomous Negotiation Targets (ANTS)
- Mobile Autonomous Robot Software (MARS)
- Software Enabled Control (SEC)
- Model-Based Integration of Embedded Software (MoBIES)
- Software for Distributed Robotics (SDR)
- Program Composition for Embedded Systems (PCES)

Networking & Distributed Systems

- Active Networks
- Next Generation Internet (NGI)
- Quorum
- Sensor Information Technology (SensIT)
- Network Modeling and Simulation (NMS)

High Performance Computing Components

- Data Intensive Systems
- PAC/C



Information Survivability

- Tolerant Networks
- Dynamic Coalitions

Ubiquitous Computing

Seedings

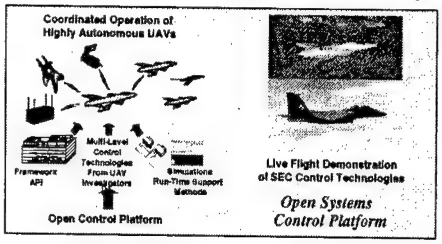
Representative Program

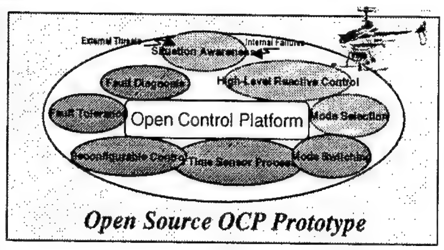
Software Enabled Control (SEC)

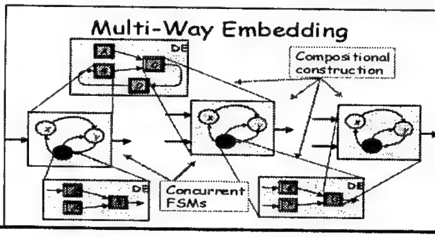
DARPA

Technology Goals:

- Control systems that we haven't been able to control before
- Increase automation for extreme maneuvers, tightly coordinated actions
- **Middleware for embedded control systems**







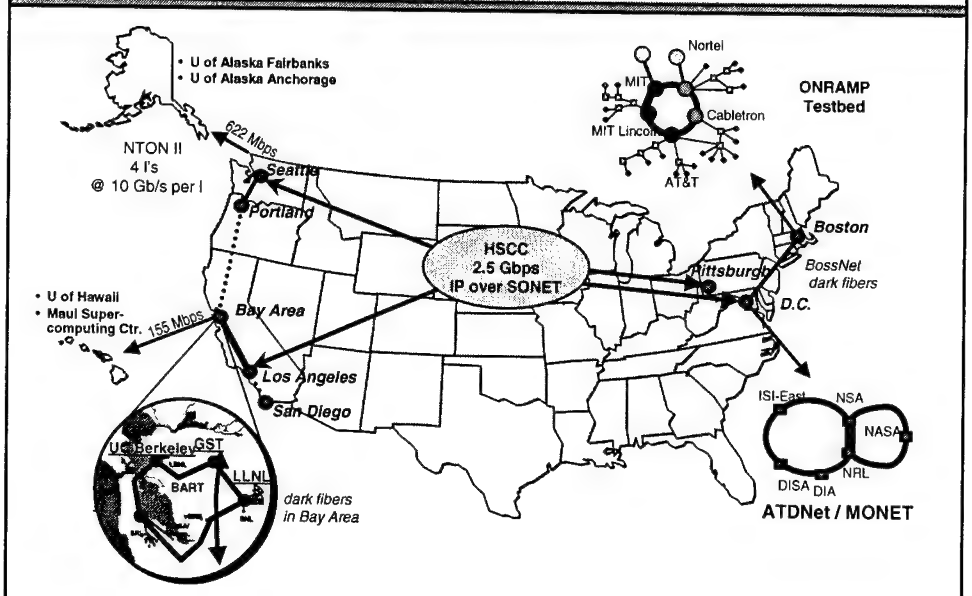
Coordinated Multi-Modal Control:

- **Control middleware (reusable)**
- Open systems, open source
- Reconfigurable hybrid (discrete and continuous) control loops
- Real-time data services for active (predictive) state models

SuperNet Testbed

(www.ngi-supernet.org)

DARPA

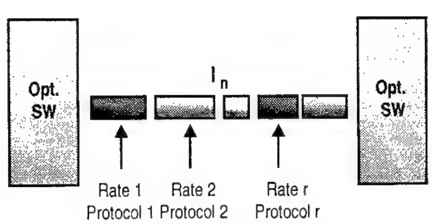


DARPA's NGI Program Components

- **SuperNet Technology**
  To enable ultra-high bandwidth on demand over national networks guaranteed over the shared infrastructure
  - Simplified protocol layering - IP over dynamic optical network
  - End-to-end performance
  - Testbed
- **Network Monitoring & Management**
  Create tools that greatly automate planning and management functions enabling networks to grow while limiting the cost and complexity of network management and control
  - Adaptive network management and control software
  - Large-scale network monitoring/analysis/visualization tools
- **Applications**
  Develop, test, deploy applications requiring gigabit end-to-end throughput

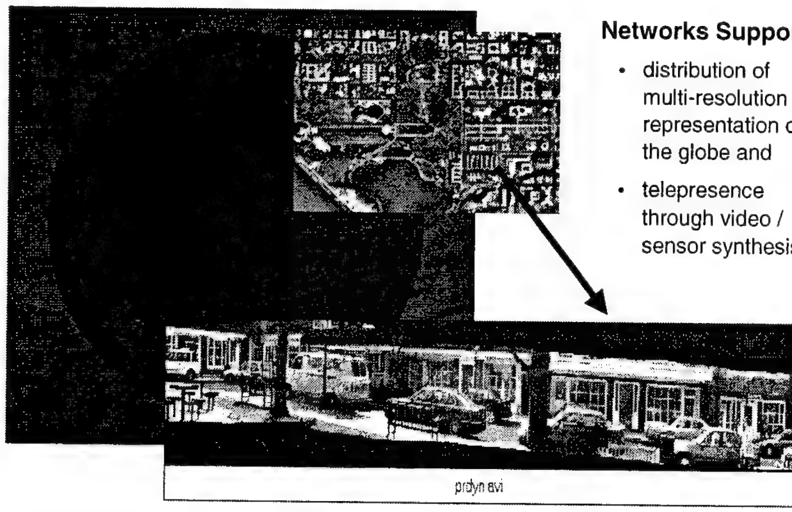
NGI Experiment: Dynamic Optical Switching

	holding time	switching speed
Reconfigurable Opt. Networking	days, months	50 msec - secs
Optical Flow Switching	>100 msec	~msec
Optical Burst Switching	>10 msec ~ 1 msec	~msec
Optical Packet Switching	> msec	~ nsec
All-Optical Switching	> nsec	~ psec



Goal: Bit rate and protocol agile

Surveillance Applications

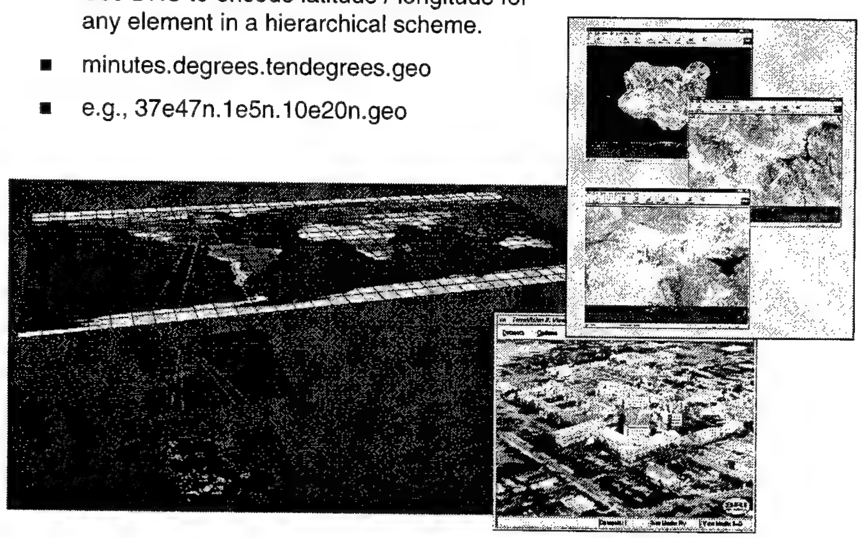


Networks Supporting

- distribution of multi-resolution representation of the globe and
- telepresence through video / sensor synthesis

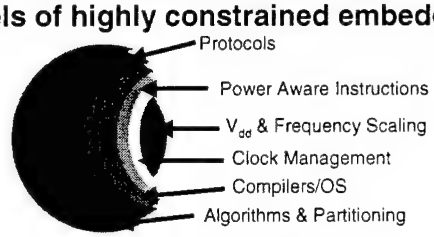
Infrastructure: .geo domain

- Use DNS to encode latitude / longitude for any element in a hierarchical scheme.
- minutes.degrees.tendegrees.geo
- e.g., 37e47n.1e5n.10e20n.geo



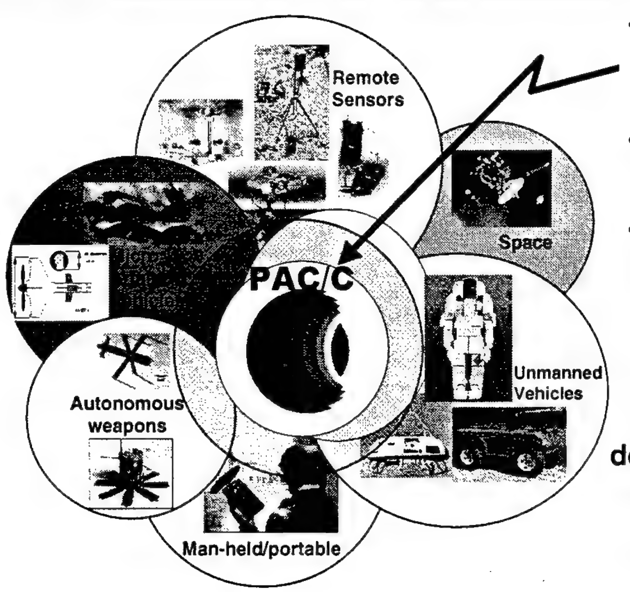
Signal Processing & Power Aware Computing/Communication

- Provide an integrated software / hardware technology suite with the potential to reduce power requirements by 100X - 1000X in (energy * delay) or performance / watt when compared to technology using conventional approaches
- Maximize energy conservation at each level while providing intelligent power aware management and optimization of energy and energy distribution at all levels of highly constrained embedded systems



Representative Program

PAC/C - Enabling Technology



- Power Aware technologies are critical across a broad range of applications.
- Broad cross section of low level technologies required
- Provide a technology suite for use by each end user

Optimize performance, energy, power demands against instantaneous mission requirements

Representative Program

Fault Tolerant Networks

Goal: Ensure continued availability of the network in the face of an attack while containing the resources available to the attacker

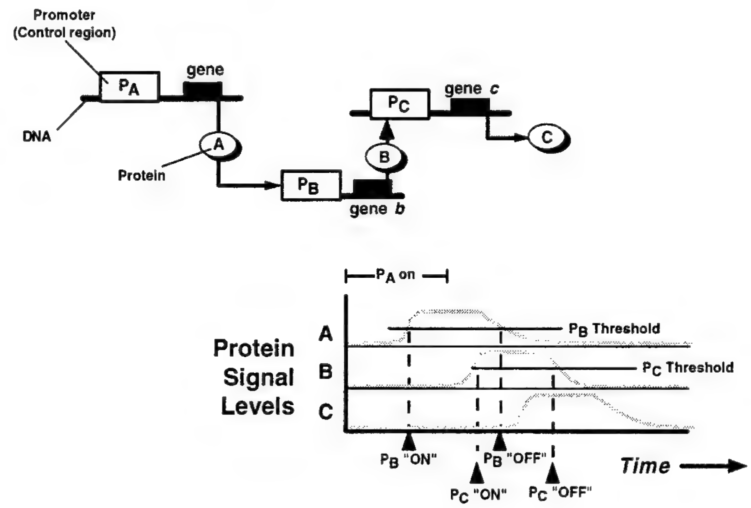
- **Fault-Tolerant Survivability**
  - Apply fault tolerance techniques to networking protocols
  - Better understanding of network fault modeling
  - Explore network overlays as survivability mechanism
- **Denying Denial-of-Service**
  - Allocation methods to constrain attacker's resource use
  - Progress-based protocols link allocation to level of trust
- **Active Network Response**
  - Exploit active networks for traceback
  - Attacker fencing

Bio-Futures
Computation in Bio-Substrate

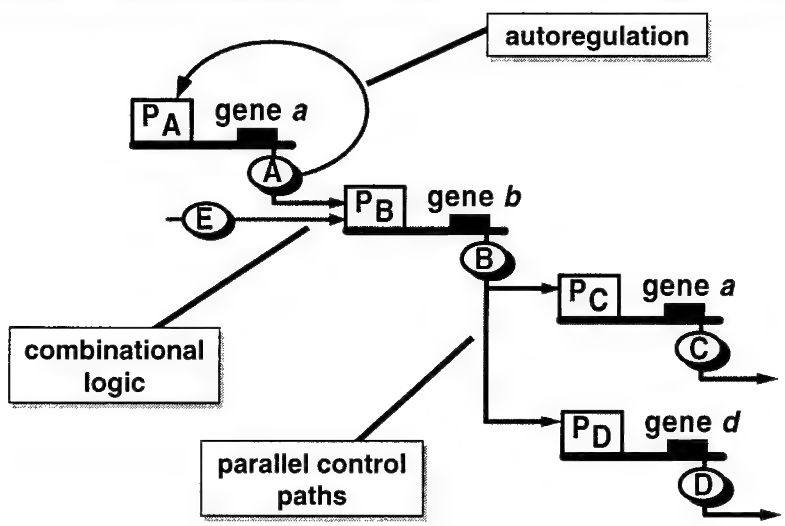
- **Hybrid Circuit Models for Biological Information Processing (Bio-Spice)**
  - Hybrid stochastic - deterministic systems
  - Gene regulation control models to predict intervention in pathogens,
  - Design optimal micro-organisms for bioreactors, biomass energy harvesting
- **DNA Computation & Devices**
  - Controlled DNA computing on substrates
    - SAT problems; bio-chips for multi-agent detection
    - Algorithmic self-assembly: sheets, cages (crystallography, molecular electronics)
  - Gates and integrated logic from DNA gene control circuits
  - Memory, databases.
- **Cellular Control systems**
  - Integrated cellular control combining
    - Sensing (aptamers)
    - Actuation (DNA lattice registers, biomotors, production of target biomolecules)
    - Local distributed control
  - Demonstrate control of physiology of normal and pathological cells
    - Sense state of cell
    - Engage gene control networks
    - Produce regulating gene products to switch cell state

Protein Concentrations Control Genetic Logic...

Genetic logic cascade

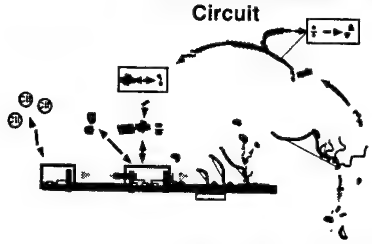


Complex Regulatory Pathways are Possible . . . .

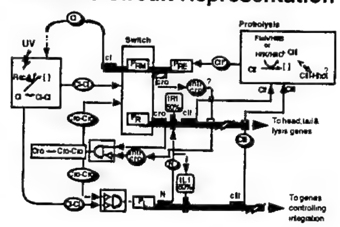


Modeling and Simulation Approach

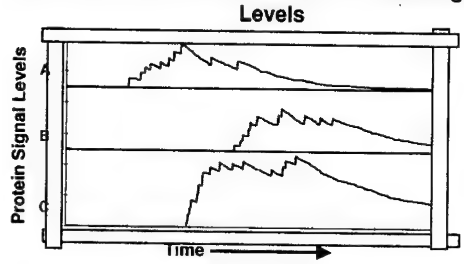
Molecular Components of Genetic Feedback Circuit



Genetic Circuit Representation



Stochastic Mechanisms Produce Fluctuating Signal Levels



Gene Regulation Networks

Science & Technology

- Develop tools for characterizing the fundamental architecture and design features underlying the dynamic behavior of genetic regulatory networks

Technology Needs

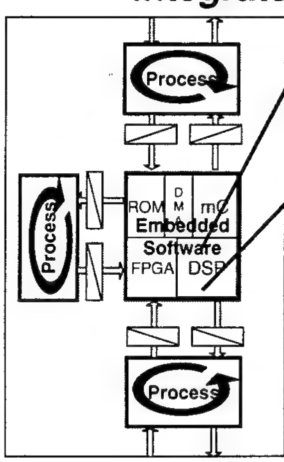
- Computer aided design tools for rational design and manipulation of metabolic systems and products
- Broad DOD payoffs
  - Rational Rx for CB and toxic agents
  - New concepts & distributed sensing and control

Embedded Software: Opportunities and Challenges

Dr. Janos Sztipanovits, DARPA/ITO

The Technology Challenge

Embedded systems: Information systems tightly integrated with physical processes



Problem indicators:
- **Integration cost is too high (40-50%)**
- **Cost of change is high**
- **Design productivity crisis**

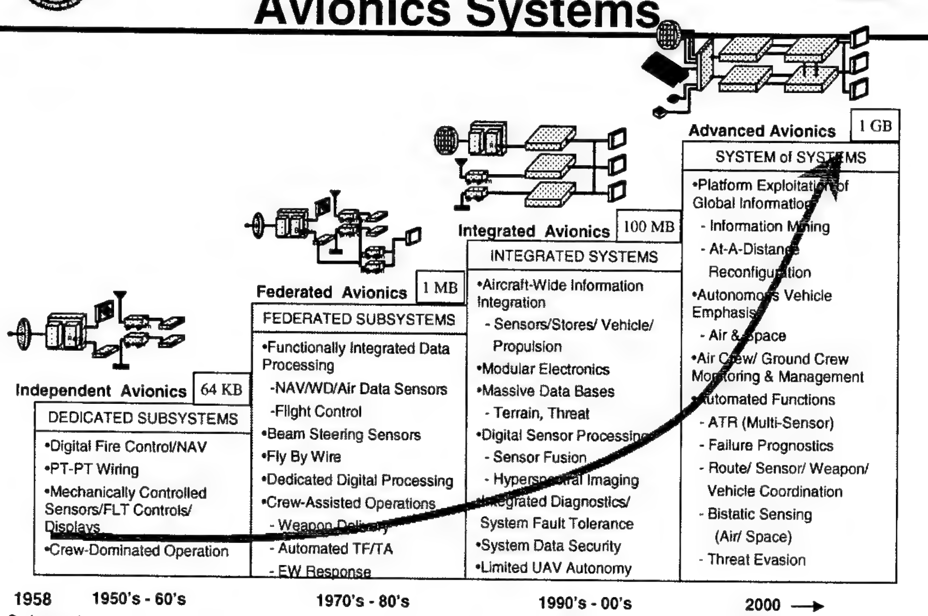
Root cause of problems is the emerging new role of embedded information systems:
- **Exploding integration role**
- **New functionalities that cannot be implemented otherwise**
- **Expected source of flexibility in systems**

Problem: Lack of design technology aligned with the new role

Problem for Whom?

- ***DoD (from avionics to micro-robots)***
  - *Essential source of superiority*
  - *Largest, most complex systems*
- ***Automotive (drive-by-wire)***
  - *Key competitive element in the future*
  - *Increasing interest but low risk taking*
- ***Consumer Electronics (from mobile phones to TVs)***
  - *Problem is generally simpler*
  - *US industry is strongly challenged*
- ***Plant Automation Systems***
  - *Limited market, conservative approach*

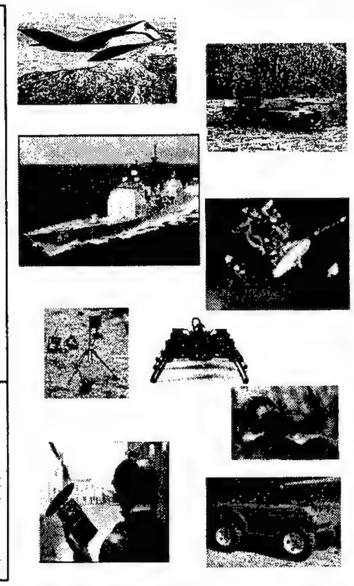
DoD Example: Avionics Systems



Source: AFRL

Technology Themes

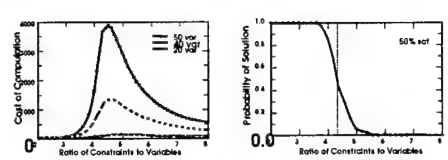
- **Software and Physics**
  - Establish composability in SW for physical characteristics; System/software co-design and co-simulation environments; New methods for system/code composition
- **Embracing Change**
  - Adaptive Component Technology; Adaptable composition frameworks; QoS middleware for embedded systems
- **Dealing with Dynamic Structures**
  - Property prediction without assuming static structures; Monitoring, controlling and diagnosing variable structure systems.



Why Can We Make a Difference?

New, critical insights in fundamentals:

Phase transitions have been found in computational requirements for solving fundamental "intractable" problems.



Emerging theory of hybrid systems provides a new mathematical foundation for the design and verification of embedded systems

$x'=f(x,u,t)$

FSM=<I,O,S,r,δ,λ>

- Model checking
- Compositional synthesis
- Simulation

Revolutionary changes in software creation: Model-based generators, aspect languages, DSL-s offer new foundation for design automation and adaptation.

Multiple aspect models

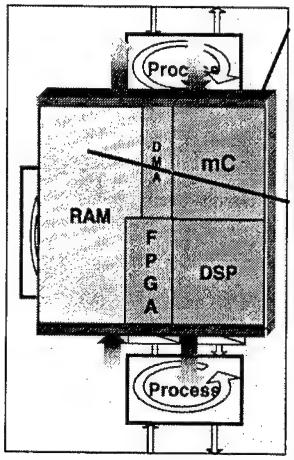
Model-based generators

Target system

- Formal modeling
- Verification tools
- Automated code synthesis

Theme 1:
Software and Physics

Embedded software: Defines physical behavior of a complex nonlinear device



Embedded System: A physical process with dynamic, fault, noise, reliability, power, size characteristics

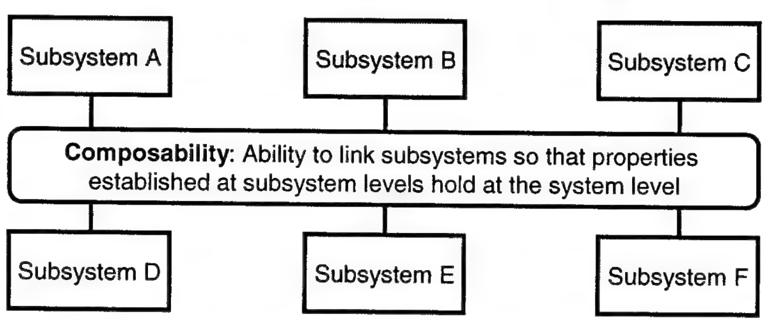
Embedded Software: Designed to meet required physical characteristics

Hard Design Problem:
- Both continuous and discrete attributes (a lot)
- Every module has impact on many attributes (throughput, latency, jitter, power dissipation,..)
- Modules contend for shared resources
- Very large-scale, continuous-discrete, multi-attribute, densely-connected optimization problem

Primary challenge: Cost-cutting physical constraints destroy composability

Why Is this a Problem?

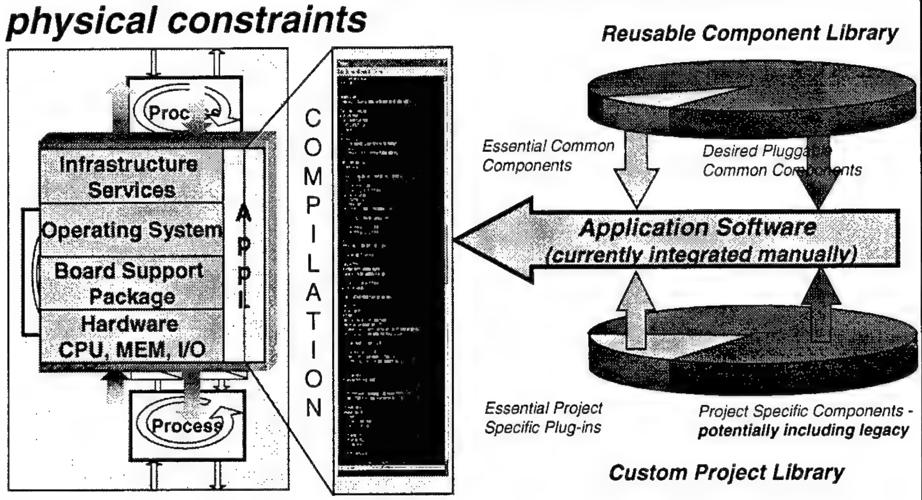
We have focused on functional composition...



But cross-cutting physical constraints weaken or destroy composability

Current Technology: Functional Composition

Functional composition does not addresses physical constraints



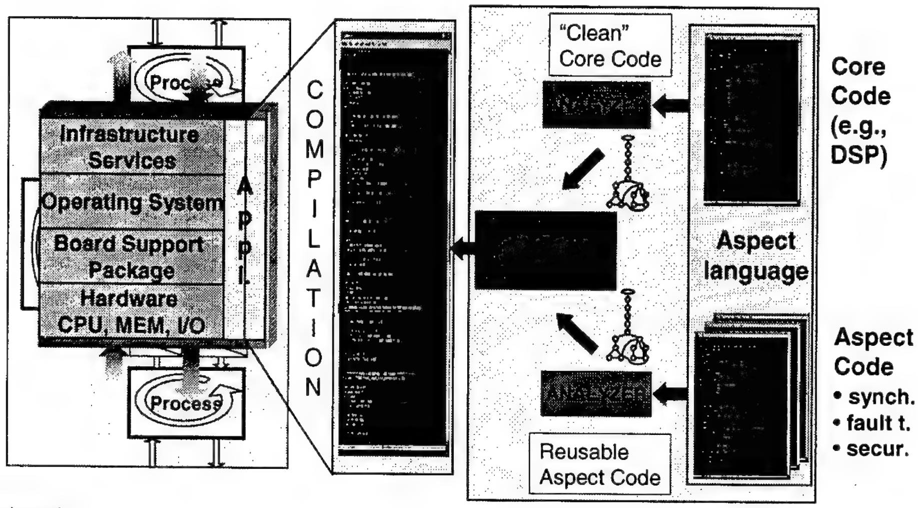
Goal: Design Automation Tools for Embedded Systems

- **Compose model-based design frameworks:**
  - Use existing CAD, EDA, CASE and systems Engineering frameworks as seeds
  - Add customizable design views and notations
  - Provide multi-resolution simulation
  - Add automated analysis and system/software synthesis
- **Capabilities:**
  - Co-evolve **integrated** physical and information system **MODELS**
  - **Synthesize/customize** software and system components **directly from models**
  - Establish **composability for physical behavior**

ITO: Program Composition for Embedded Systems (PCES)

DARPA

Aspect languages will change programming:

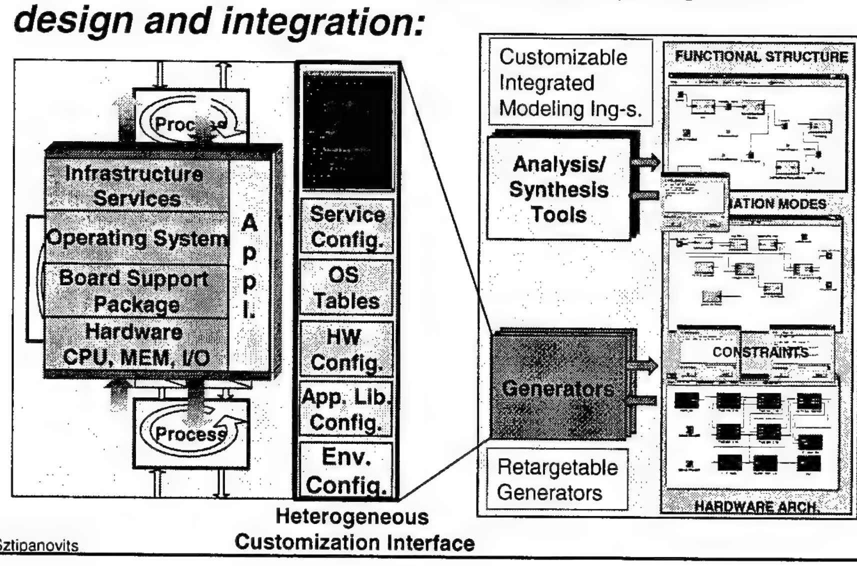


J. Sztipanovits

ITO: Model-Based Integration of Embedded Software (MoBIES)

DARPA

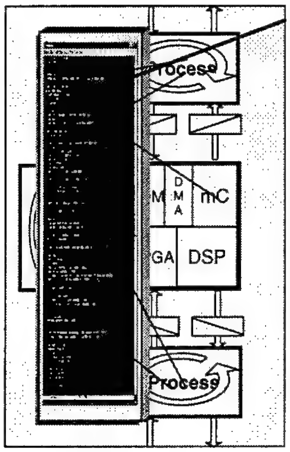
Model-based integration will change system design and integration:



J. Sztipanovits

Theme 2: Embracing Change

Source of change: environment, requirements



Hard Problem: Due to its integration role, system-wide constraints accumulate in software:
- Process properties - algorithms, speed, data types
- Algorithms, speed, data types - resource needs
- Shared resources - speed, jitter,..

..scattered all over the software.

Condition for managing change:
- Constraints need to be explicitly represented
- Effects of changes need to propagated by tracking constraints

Flexibility is essentially a SYSTEM-WIDE CONSTRAINT MANAGEMENT PROBLEM

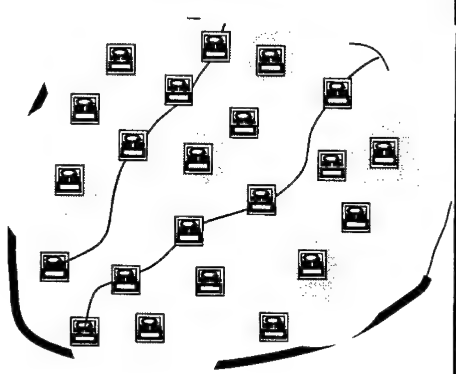
Goal: Adaptive Component Technology for Embedded SW

- **Builds on object component technology (CORBA, COM) but provides:**
  - Internal mechanisms to respond to changes
  - Physically and computationally "self-aware" components
- **Capabilities:**
  - Insulates software from hardware with small performance penalty
  - Increases tolerance to unexpected changes
  - Optimizes performance
  - Increases tolerance to faults

Theme 3: Dealing With Dynamic Structures

A new category of systems:

Embedding +
Distribution +
Coordination

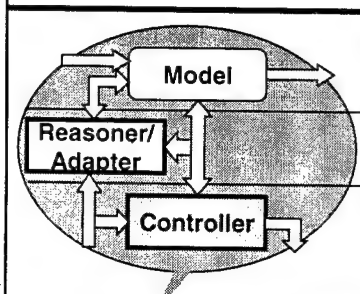


LARGE number of tightly integrated, spaciously and temporarily distributed physical/information system components with reconfigurable interconnection.

Why should we work on this?
The wave is coming:

- Tremendous progress in MEMS, photonics, communication technology. **We need to build systems now from these.**
- Identified applications with **very high ROI: strong application pull**
- **Almost total lack of design theory technology: The problem is extremely hard.**

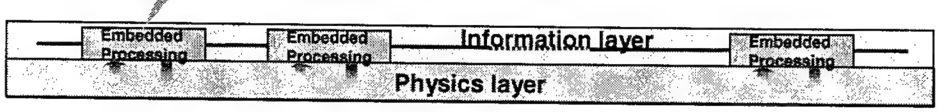
Problem Abstraction



Model: Locally and globally relevant information for global coordination

Reasoner/Adapter: Adaptation of local structure and parameters, coordination

Controller: Discrete or hybrid control of local physics



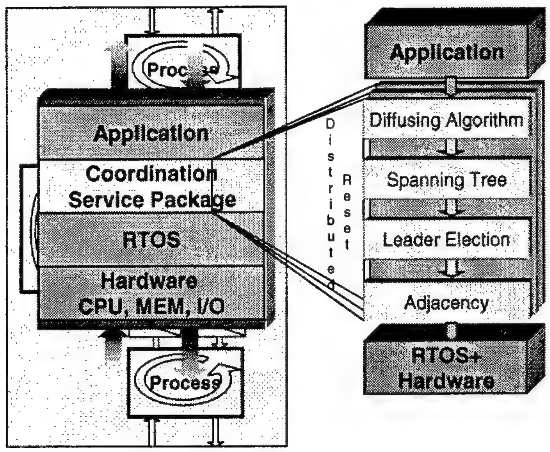
Distribution:

- Heterogeneous, simple components (10^2-10^5)
- Changing interconnection topology
- **Embedded synthesis** for dynamic distribution, reconfiguration

Coordination:

- Global **coordination** of local interactions
- Consistency of globally relevant information
- Requirements are determined by locality of physics

Goal: Services for Coordination

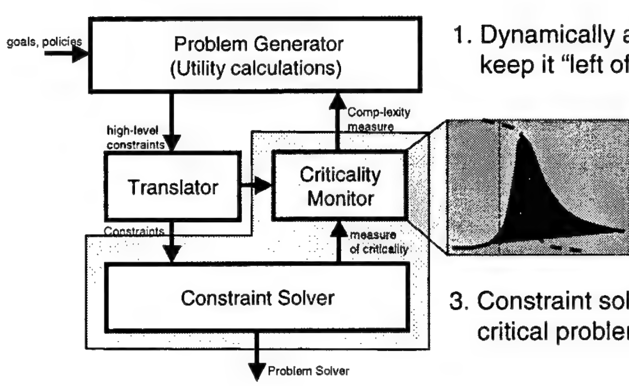


- Applications determine the type of services required
- Physical characteristics of the system determine dynamics, accuracy and required fault behavior of services
- Services are built in layers with rich interdependence
- Algorithms used in components depend on the distributed computation model

Hard Problems: Hybrid self-stabilization, customizable design, predictable dynamics, time bounded synthesis, automated composition.

Practical Use of Phase Transitions:
Approach to Synthesis Services

Approach: Transition-aware, sub critical problem solver
Challenge: Problem statistics, order parameter.



1. Dynamically adjust the problem to keep it "left of the phase transition".
2. Criticality monitor gives assessment of problem complexity using simple analysis methods.
3. Constraint solver rapidly solves sub-critical problem instances.

What Are We Doing?

Software and Physics
- System/Software co-[design,simulation, analysis]-
- New methods for system/code composition---------
- Frameworks and middleware for embedded SW---
- Hybrid optimization,analysis----------------------------

Embracing Change
- Adaptive components for embedded systems------
- Methods for controlling flexibility-----------------------
- Adaptable frameworks and QoS middleware-------
- Programming methods to achieve flexibility---------

Networked Embedded Systems
- Predicting global properties from local component descriptions without assuming static structures---
- Monitoring, controlling and diagnosing of variable structure hybrid systems-----------------------------------
- Dynamic composition frameworks and middleware for networked embedded systems--------------------
- Controlling physical, chemical and biological properties via embedded information processing---

Relevant existing programs:
(MoBIES, PCES, SEC)
- Coordinate efforts
- Leverage to increase common technology base
- Primary impact on Themes 1-2

New-start program:
- **Networked Embedded Systems Technology (NEST)**

Planned program:
- Adaptive and Reflective Middleware Systems

Conclusion

- **Embedded Software is an important area for DARPA due to the exploding integration role of information technology across military platforms.**
- **Existing and planned programs establish a new re-integration of physical and information sciences. This will make a huge difference in our ability to:**
  - Design software for achieving physical behavior,
  - Make software able to absorb change in physical systems,
  - Build, integrate physical systems dynamically from spaciously and temporarily distributed components.
- **To do this means changing culture. DARPA's focused investment is critical to catalyze and accelerate this process.**

Future

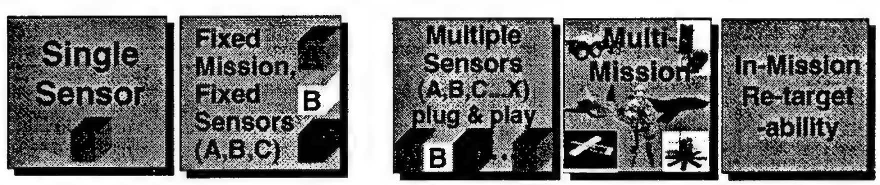
Embedded Computing

Architectures

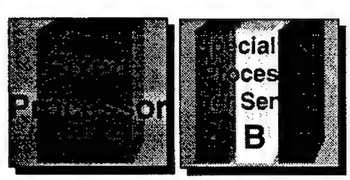
Robert B. Graybill
Program Manager
DARPA/ITO

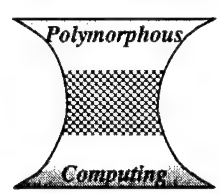
Embedded Computing System Requirements Revolution

Have | *Could Have*

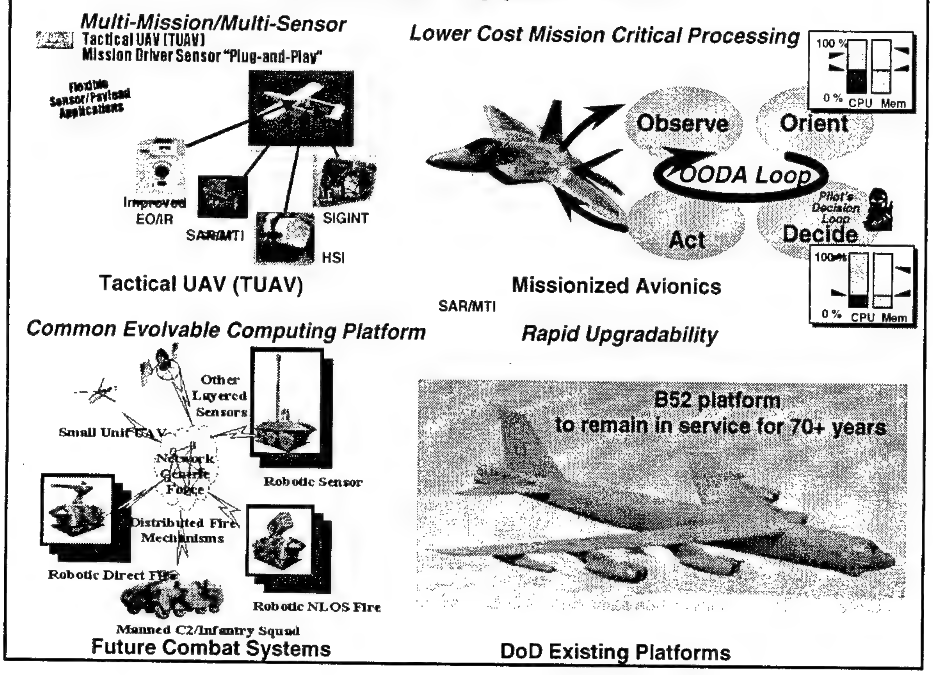


BOUNDED MISSION CAPABILITY | DYNAMIC MISSION CAPABILITY

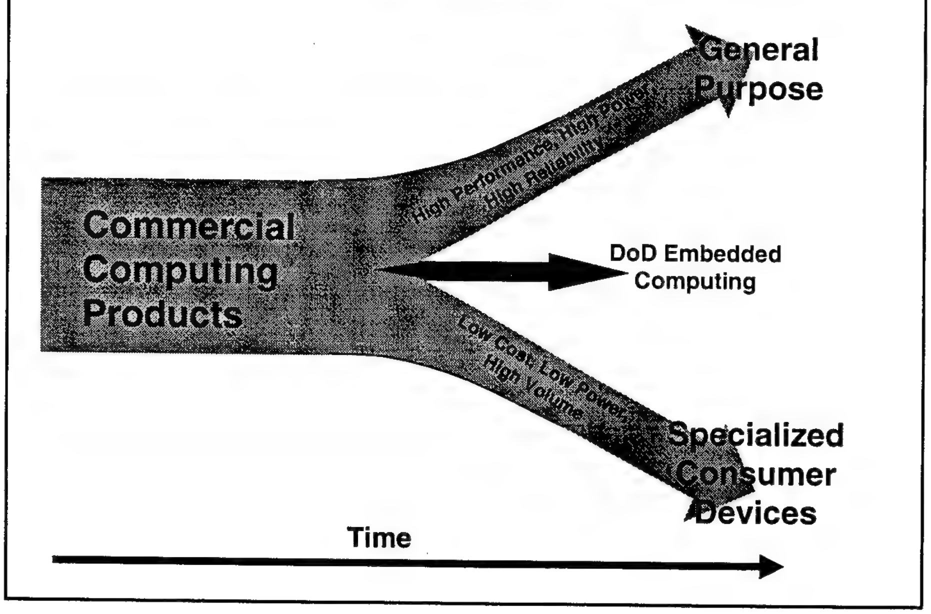




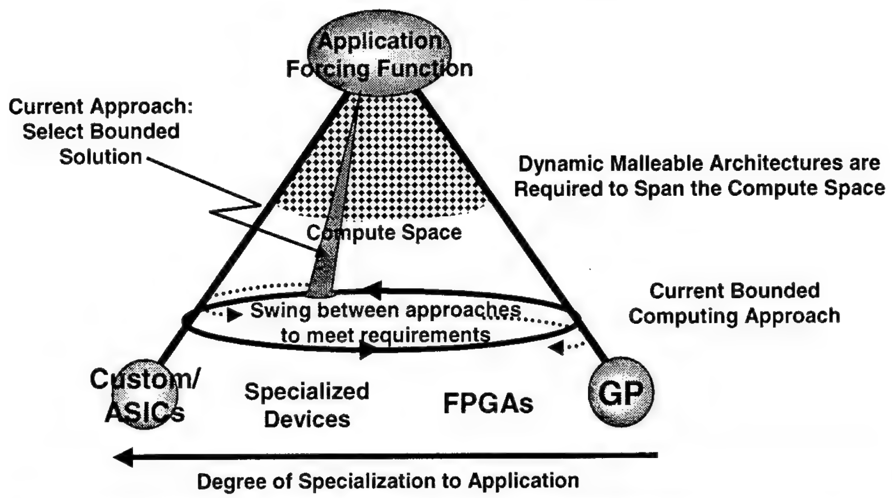
Challenge Applications



Commercial Support of DoD Computing Requirements

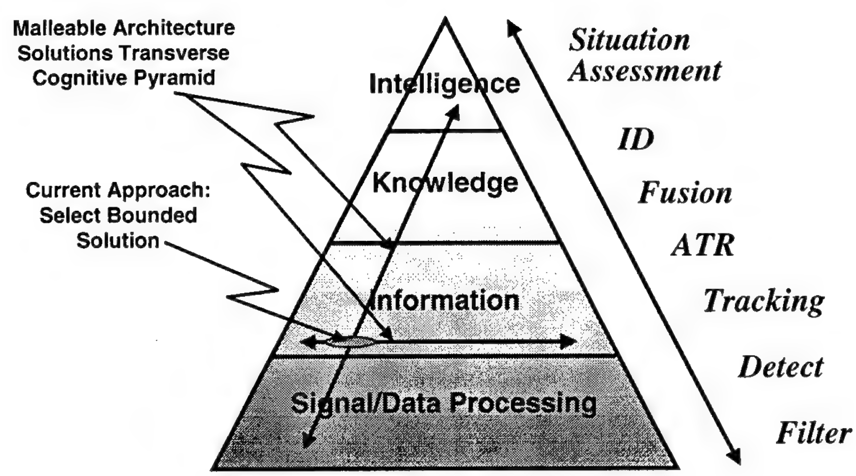


Current Architecture Solutions

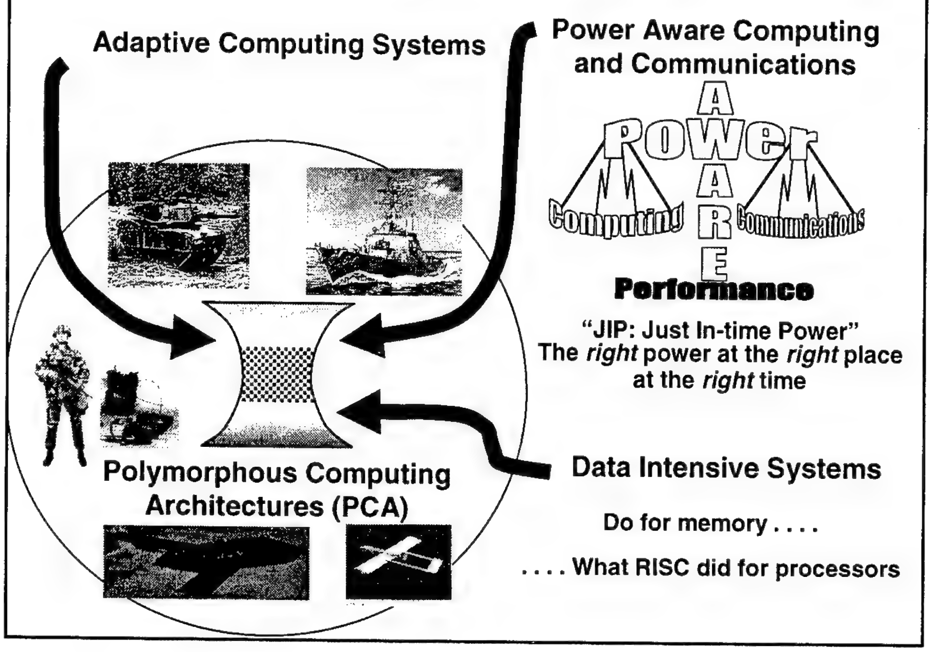


New Class of Missions Require a Transversal of the Architectural Space

New Class of Missions Require Application Space Diversity

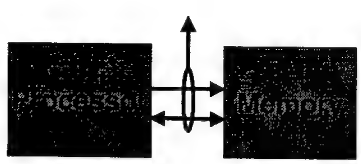


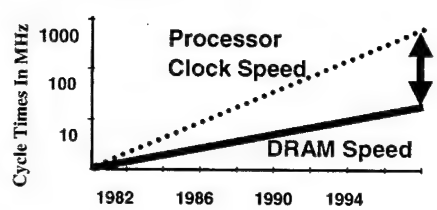
Mission Aware Embedded Computing Activities



Data Intensive Systems

The Problem: Data-Starved Defense Applications

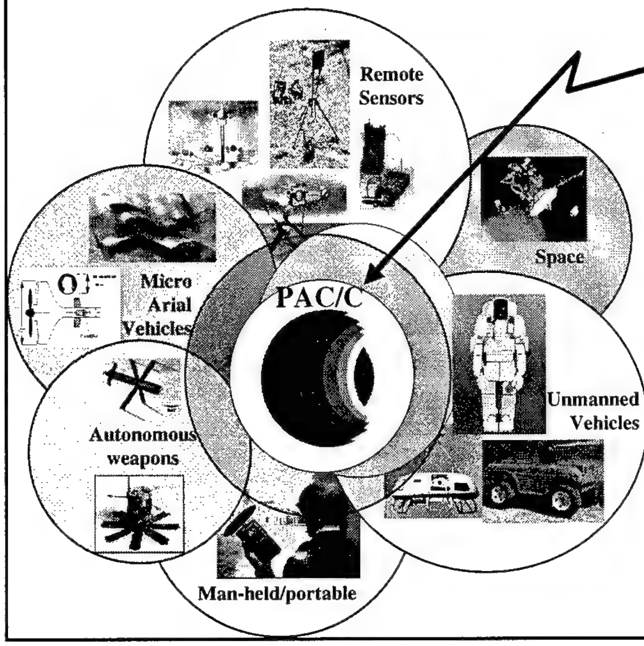




Solution:

- **In Situ Processing**
  - ***Logic within memory chips*** **manipulates data within the memory subsystem**
  - ***Memory within computational streams***
- **Adaptive Cache Management**
  - ***Applications manage memory*** **hierarchy so data placement and control flow is tailored to application specific needs**

PAC/C - Enabling Technology

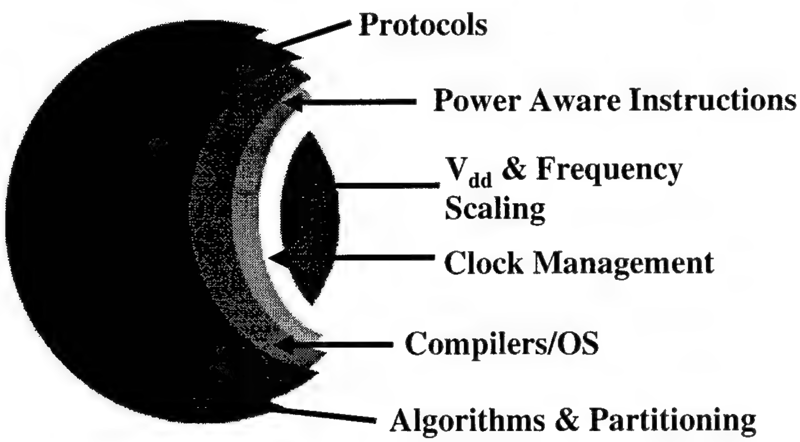


- Implement Power Management at all levels
- Provide a technology tool suite for use by each end user
- Power Aware technologies are critical across a broad range of applications

Optimize *performance, energy,* and *power* demands against instantaneous mission requirements

PAC/C Approach

Power Aware Technology at All Levels



Polymorphous Computing Architectures (PCA)

Enable reactive multi-mission and in-flight retargetable embedded information computing systems that will reduce mission computing payload adaptation, optimization, and verification from years to months to minutes.

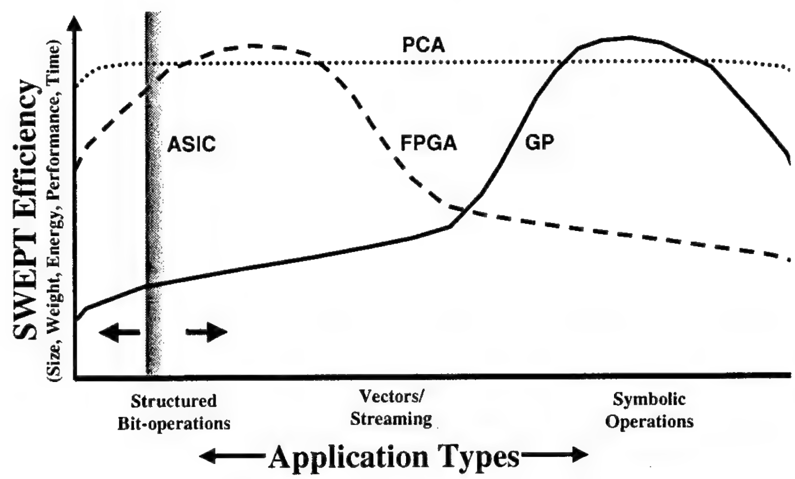
Polymorphous Computing

Polymorphic - ***Adj. having, taking, or passing through many different forms or stages. (Greek polus many + morphe form)***

Polymorphous Computing Architecture (PCA)

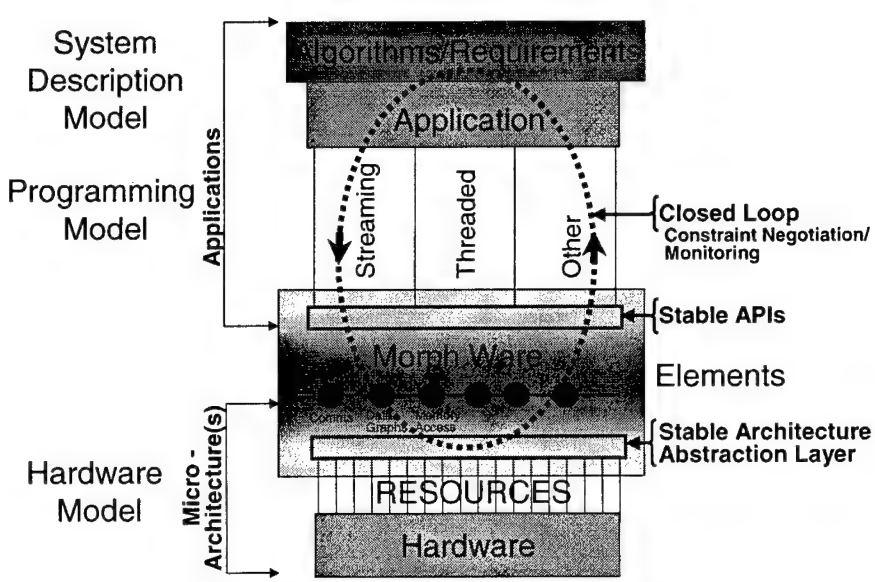
- **What will we do?** Develop an adaptable (polymorphic) middleware/micro-architecture that can rapidly adapt as required.
- **How is this different?** Today's embedded computing systems are generally optimized using a static architecture.
- **What is the impact?** Provide the warfighter the ability to always have access to the best available embedded computer capability:
  - Ease of HW upgrade throughout the platform's lifecycle
  - Rapid multi-mission/multi-sensor adaptability.
- **What is the product?** Provide a validated (via prototype testing) suite of polymorphic computing architectures (PCA) technologies for DoD embedded computing applications.

Efficiency versus Application Space



Hard Problem: Optimized Performance Over Broad Application Space

PCA Architecture Concept

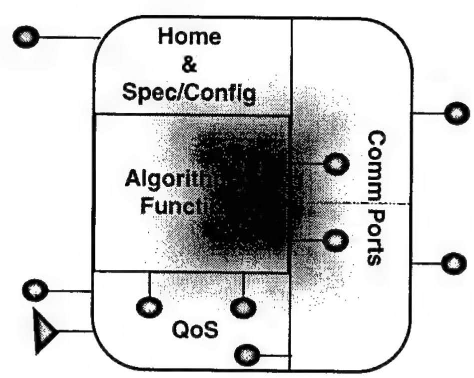


Abstract Hardware Model Presented to Software

- **Must present a range of abstractions**
  - Compute
    - Vector to multi-processor machines
  - Communication
    - Circuit switch to packet router
  - Memory
    - Vector registers to caches
  - Verification
    - Functionality to performance metrics

Support Broad Range of Models

Polymorphous Software Component



Measurable and Verifiable Configurations/Behavior

PCA Enables

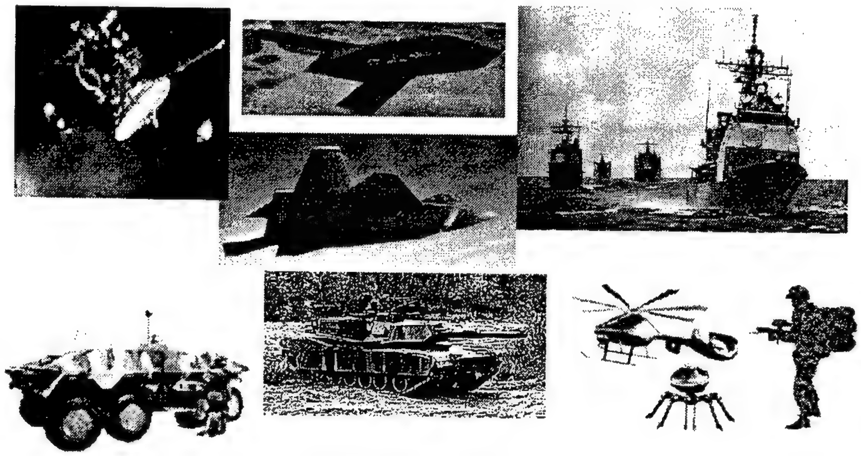
- Multi-mission, multi-sensor, and in-mission reconfiguration
- Rapid technology insertion
- Deterministic behavior within SWEPT (Size, Weight, Energy, Performance, Time) constraints
- Component based validation
- Preservation of software investment

Forever Change the Way DoD Develops Embedded Software & Hardware Computing Systems

Summary - Future Directions -

	New Ideas
■ Embedded Computing	➡ Polymorphous Computing
■ High Performance Scientific Computing	➡ Fill the Technology Research Pipeline ?

Multi-Mission Environments and Polymorphous Architectures



Laying the Embedded Computing Technology Foundation for the Dynamic Battlespace

Secure Networking

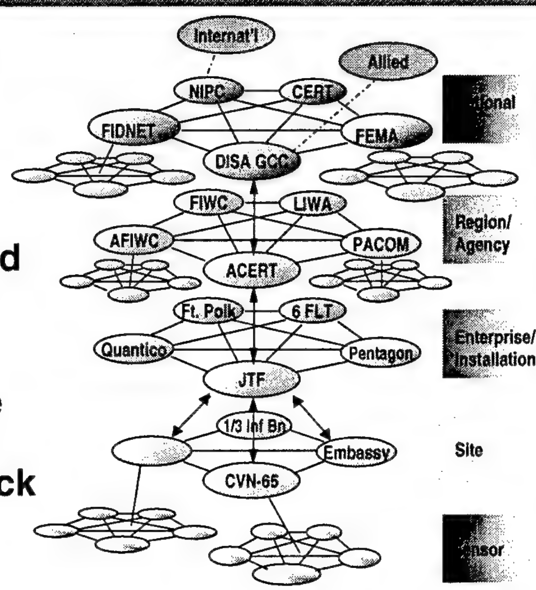
Dr. Douglas Maughan

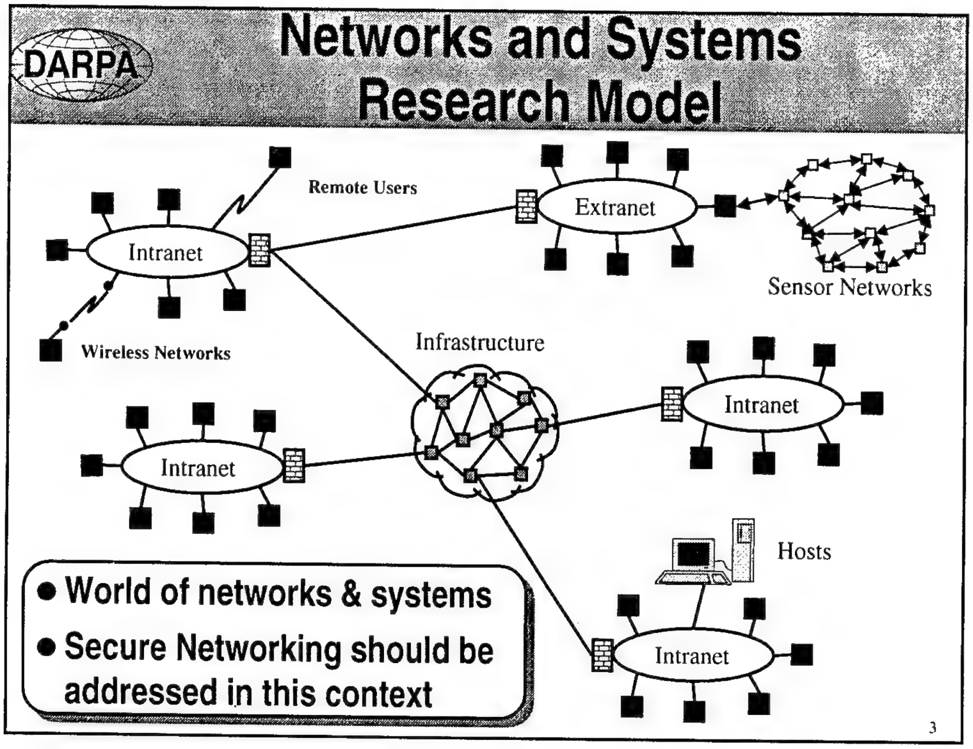
DARPA / ITO

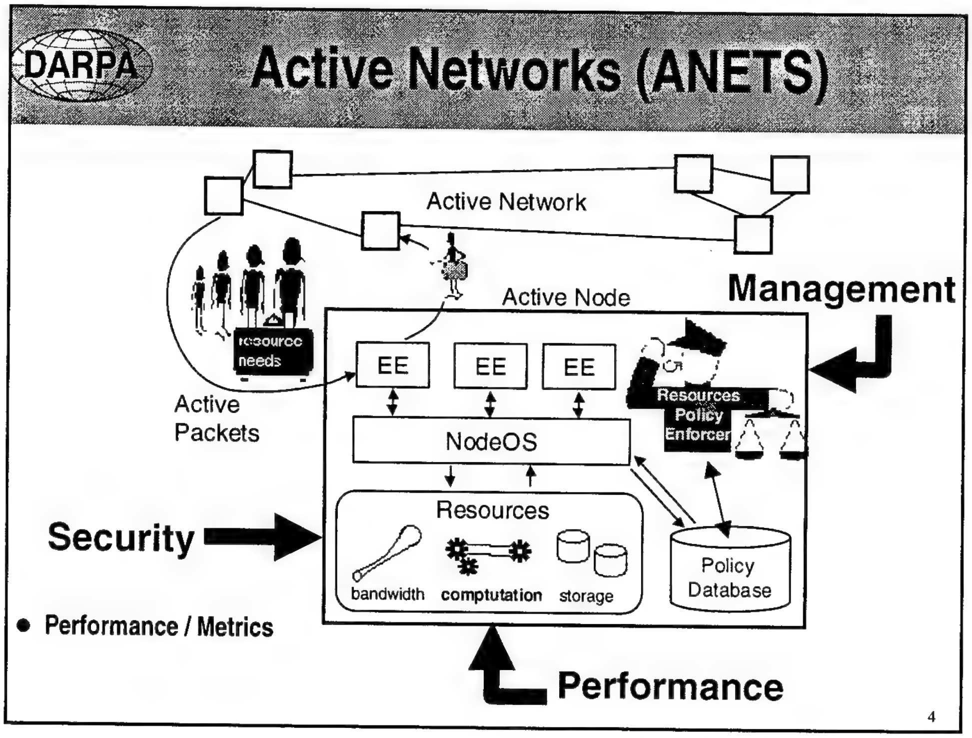
dmaughan@darpa.mil

Network Reliance is Pervasive

- DoD depends on networking technology for information dominance at all levels of command hierarchy, BUT ...
- DoD networks are increasingly vulnerable to attack



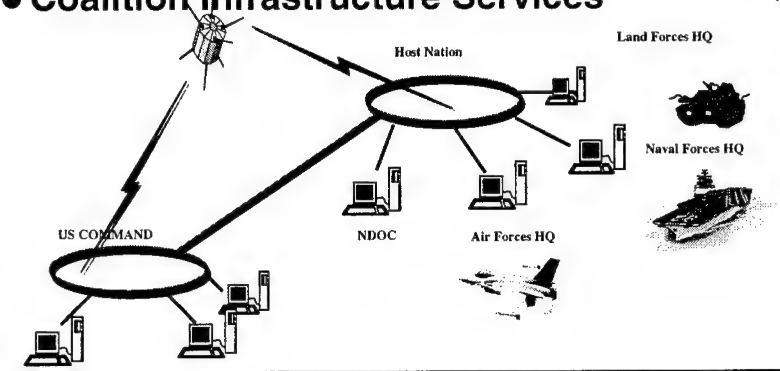

DARPA
Networks and Systems Research Model
Remote Users
Extranet
Intranet
Sensor Networks
Wireless Networks
Infrastructure
Intranet
Intranet
Hosts
Intranet
• World of networks & systems
• Secure Networking should be addressed in this context
3


DARPA
Active Networks (ANETS)
Active Network
Active Node
Management
resource needs
EE
EE
EE
Active Packets
Resources Policy Enforcer
NodeOS
Resources
Security
bandwidth
comptutation
storage
Policy Database
• Performance / Metrics
Performance
4

Dynamic Coalitions (DC)

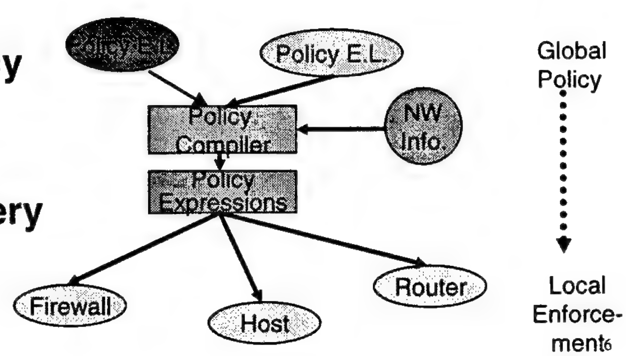
Goal: Manage dynamic coalition formation and secure sharing by authorized members

- Multi-Dimensional Coalition Policies
- Secure Group Management
- Coalition Infrastructure Services

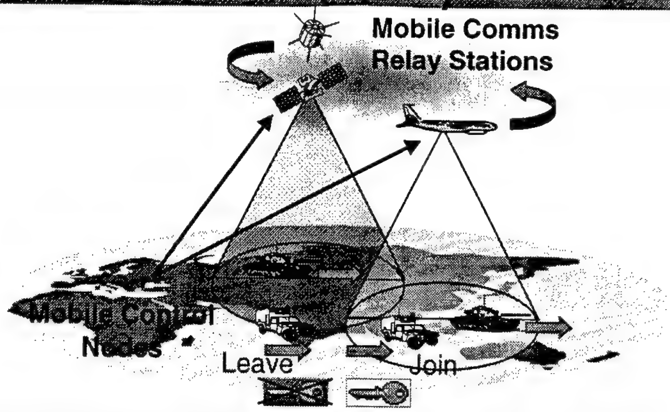


Multi-Dimensional Coalition Policies (MDCP)

- Establish "standard" language for policy expression
- Capability to negotiate policies with potential coalition partners (implies multiple at same time)
- Dynamic policy management
  - Multi-game
- Policy discovery



Secure Group Management (SGM)



- New techniques for sender authentication
- Scalable distribution - group creation & re-key
- Leverage secure multicast standards work

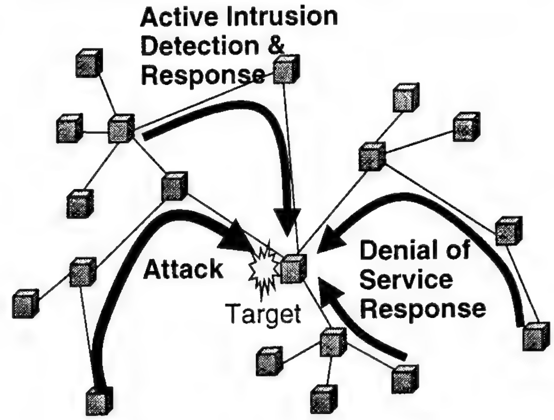
Coalition Infrastructure Services (CIS)

- Scalable techniques for timely propagation of revocation information (e.g., compromised keys, expired certificates, etc.)
- Extend current technologies of cross-certification for rapid coalition deployment capabilities
- Secure identification/trust technologies (e.g., credentials)

Fault Tolerant Networks (FTN)

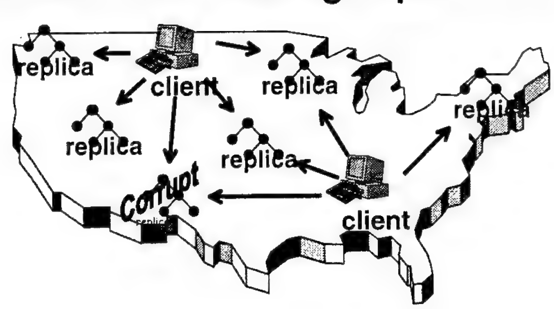
Goal: Ensure continued network availability in the face of attack while containing attacker resources

- **Fault-Tolerant Survivability**
- **Denying Denial-of-Service**
- **Active Network Response**

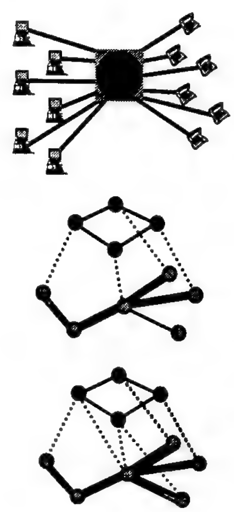


Fault-Tolerant Survivability (FTS)

- **Replication and partitioning of network services; Redundancy of network resources**
- **Better understanding of network fault modeling**
- **Survivable virtual network overlays**
- **Create network self-healing capabilities**



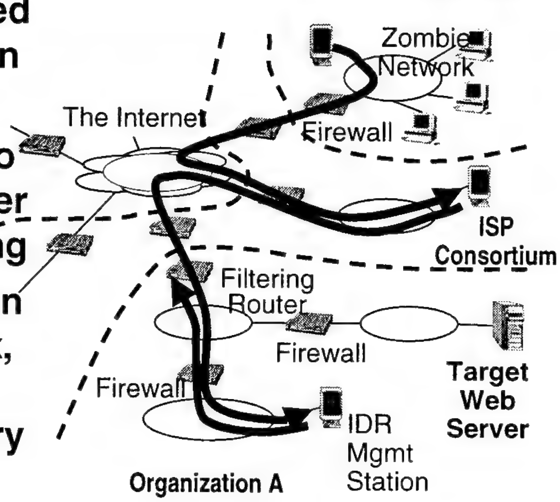
Denying Denial-of-Service (DDOS)



- Develop market-based resource allocation strategies to limit resource consumption by attacker
- New communication protocols that execute based on incremental progress within trust chain
- Create accurate mechanisms for reliably attributing DoS attacks
- Harden current routing and naming infrastructure protocols against DoS attacks

Active Network Response (ANR)

- Leverage advanced intrusion detection techniques
- Active networks to assist with attacker tracing and fencing
- Immediate reaction to real-time attack, limiting damage and begin recovery



Survivable Mobile Wireless Networking

DARPA

Ensure future mobile, wireless networks are resistant to attacks via dynamic and adaptive configuration strategies

- Develop capabilities for dynamic, survivable wireless network establishment
- Leverage wired information assurance solutions
- Create survivable key management capabilities to protect against compromise and enable rapid recovery and reconstitution
- Develop node adaptation strategies leveraging active networking

Summary / Conclusion

DARPA

- Networking technology is the cornerstone of DoD communication architectures of the future (e.g., JV 2010, JV 2020)
- Increasing environments of collaboration require technologies for secure sharing of data and resources
- Networks at all levels of command hierarchy must be resistant to attack and "operate through" those attacks which are successful

Secure Networking

Dr. Douglas Maughan

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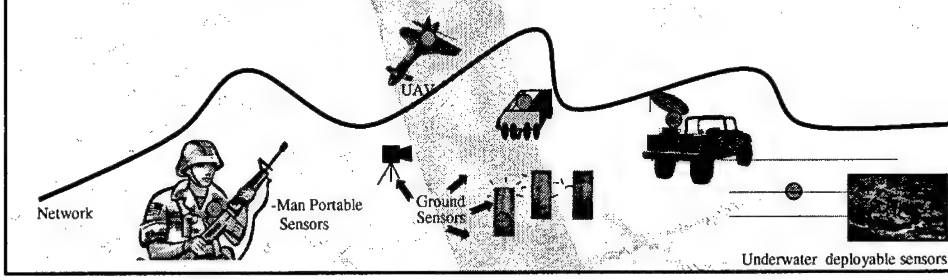
SensIT: Sensor Information Technology

Networked Micro Sensor Technology
21 Ideas for the 21st Cent. Business Week. 8/23-30, 1999

Program: Rapid and Accurate Information Technology Enabling Networked Detection, Tracking of Threats

DARPA/ITO
PM: Sri Kumar



Sensor Information Technology

Goal

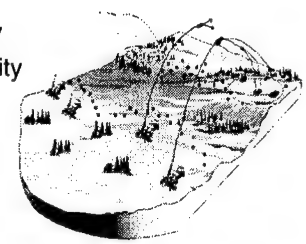
Software for distributed Micro Sensor Networks

Thrusts

- New networking methods
- Leverage distributed computing paradigm for
  - Reliable extraction of right and timely information from sensor field
  - Networked signal and information processing
  - Dynamic querying and tasking

Software Supporting New Capabilities

System Parameters
- Latency
- Energy
- Autonomy
- Survivability

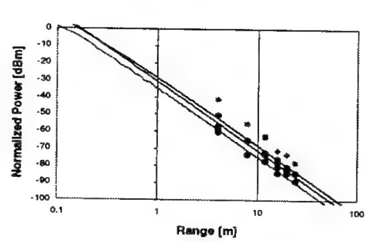


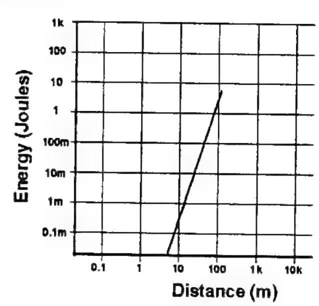
Low-Cost, Rapid, and Accurate:
- Detection
- Identification
- Tracking
- Targeting
- Communication to overhead asset

For Networked Micro-Sensors
- Interactive
- Programmable
- Multi-Tasked
- Short Range
- Algorithms to exploit proximity of devices near threats
  - drastically improved S/N
  - exploit multi-modal sensors
  - collaborative processing

Environment

- Operating Conditions
  - Harsh, Uncertain, Dynamic: Adaptive
  - Autonomous Operation
    - Scale: Too many devices for manual configuration
- Dynamic availability of resources
  - Energy/Power, BW, MIPS Constraints





Challenges

- **Networking**
  - Reliable, Survivable, Secure
  - For Ad-Hoc, Rapidly Deployable Devices
  - Seamless Fixed/Mobile Device Interaction
- **Networked Computing**
  - Extract Useful Information from Sensor Field
  - Collaborative Processing
  - Dynamic Query, Tasking
  - Reliable and Efficient

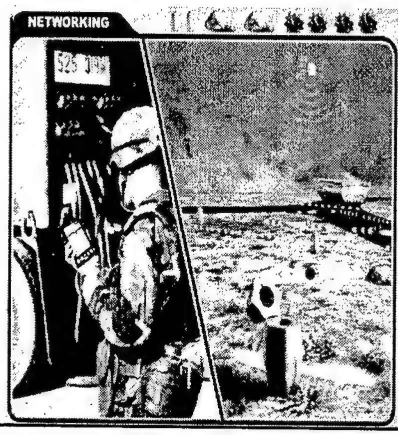
SensIT: Tasks

- Networking
- Collaborative Signal Processing
- Query/Tasking
- Software Integration/Experimentation

Networking: Fixed Sensor Devices

Characteristics:

- Ad-hoc, self-assembled
  - minimal state; IP-alternative
- Low-latency
- Survivable, secure



New Approaches:

- No IP-address
  - No global topology
- Data-centric vs. end-end connections
- Application specific
- Survivability, adaptation through redundancy
- Diffusion routing

Tradeoffs:

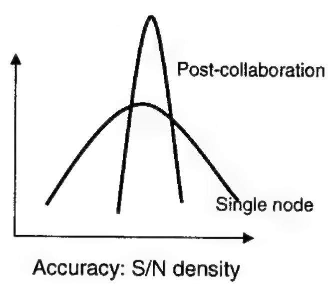
- Latency
- Reliability
- Power/Energy?

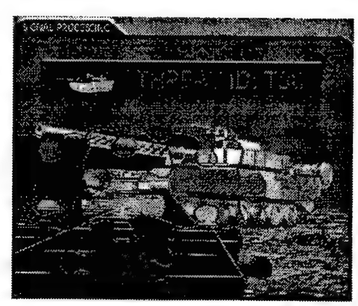
Deployment Density/Size?

- Scaling effects

Collaborative Information Processing

- Exploit Dense Spatial Sampling
  - Networked Consensus
- Distributed Signal Processing Algorithms
  - Asynchronous
  - Progressive Accuracy
  - Efficient: Energy, BW, MIPs
- Deployment Density
  - Performance
    - How does it scale?





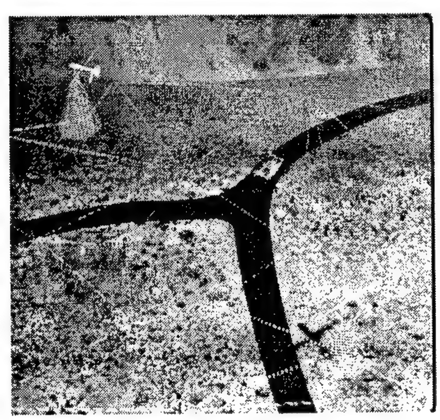
Querying and Tasking

- Simple User Interface
  - Query/Tasking Language
- Query/Task Processing
  - Distributed; Multi-tasking
- Distributed Micro Database
  - Data Organization
  - Placement and Caching
  - Scalable
- Capacity

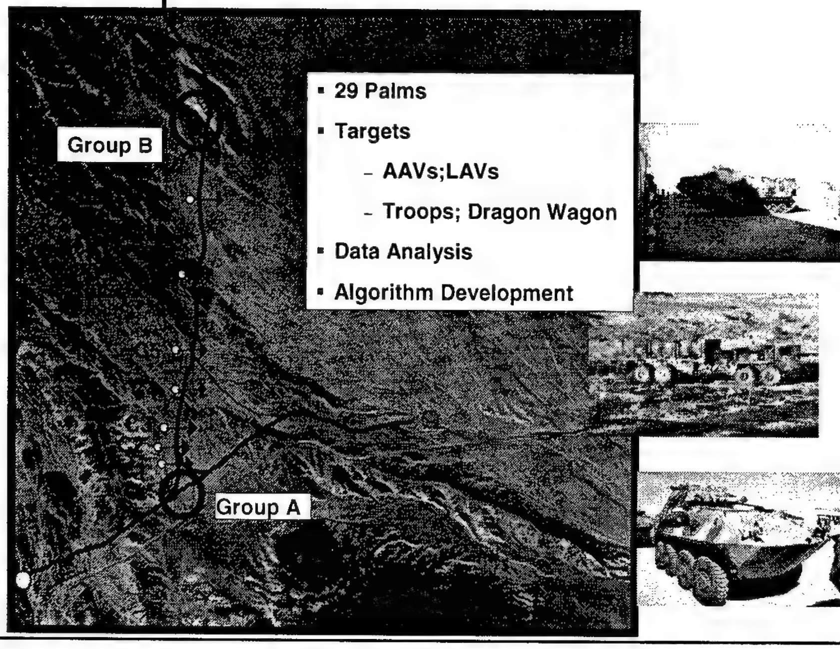
Fixed/Mobile – Internetworking

- Discovery (Identity, Services)
- Engagement (Fixed/Mobile)
  - Single Point/Multi-Point
    - **Handoffs**
  - Depth of Engagement
    - **Edge**
    - **Deeper**
  - Planned and Ad-hoc
  - Intermittent Connectivity
- Leveraging Mobility
  - Cueing; Fill Holes
  - When and Where; Task/Code Migration

Mobile Sensors, Mobile Query



Experiments: Field, Lab



- 29 Palms
- Targets
  - AAVs;LAVs
  - Troops; Dragon Wagon
- Data Analysis
- Algorithm Development

SensIT: Impact

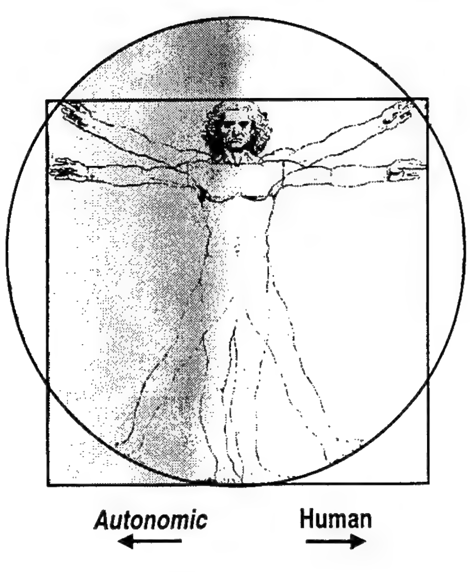
- **Function**
  - Detection
  - Identification
  - Location
  - Tracking
- **Targets**
  - Personnel
  - Wheeled/Wing
  - Tracked
- **Environment**
  - Open field
  - MOUT
- **Users**
  - Dismounted soldiers
  - Command post
  - Force level
  - Intelligence
- **Application**
  - Personal
  - Platoon
  - Battalion
  - Border and base security
  - Air campaign
  - Land mine replacement

Embedded IT Enabling Revolution in Networked Sensing

Information Systems Office

Dr. W. M. Mularie
Director, Information Systems Office
703-696-7438 • wmularie@darpa.mil

Information Systems Prosthetic

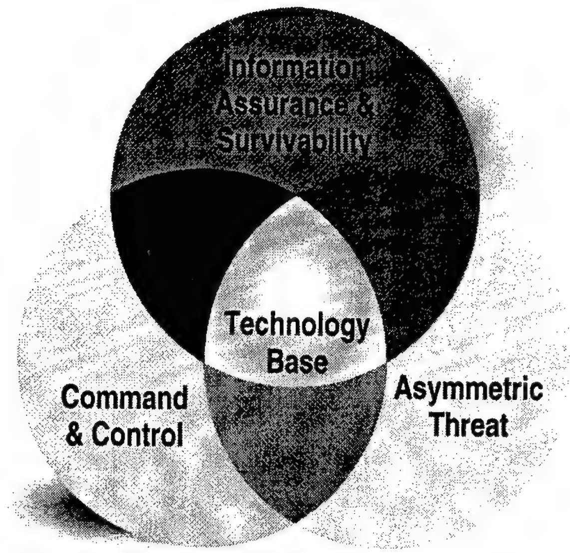


Autonomic ←   Human →

Challenge:
Overcome Human Limitations

- Speed
- Complexity

ISO Program Areas



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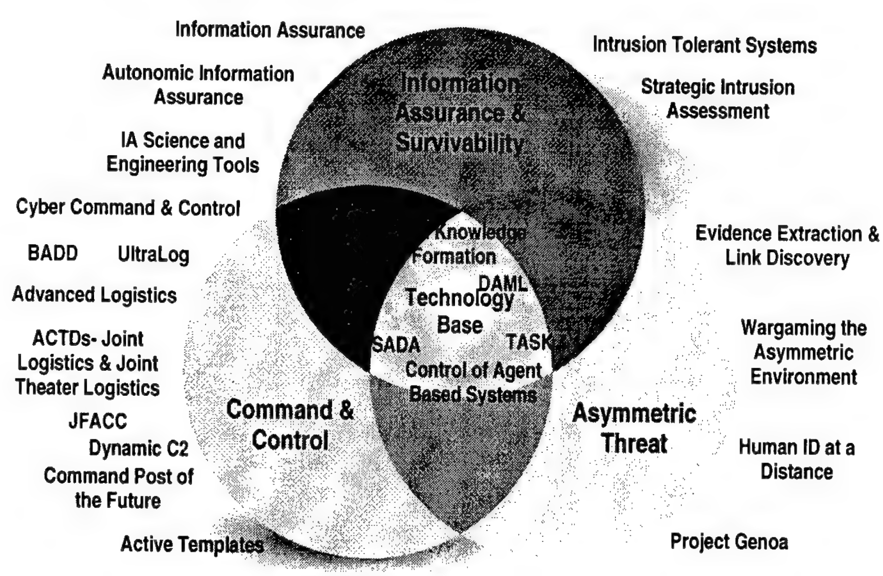
ISO Program Areas



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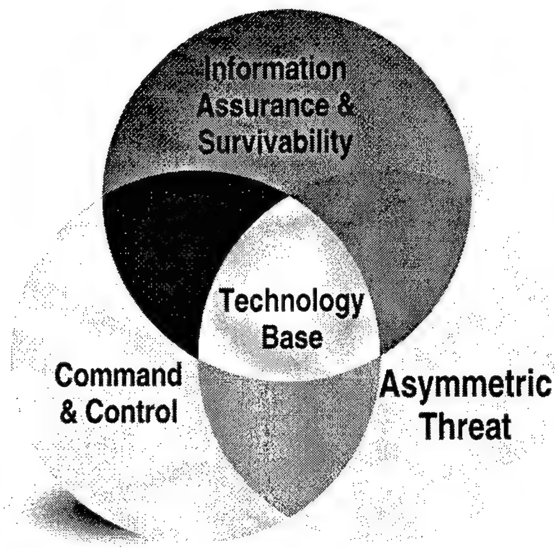
ISO Program Areas



Unconventional yet highly lethal attack by a loosely organized group of transnational terrorists

5

The Nuclear Threat
A Historical Perspective

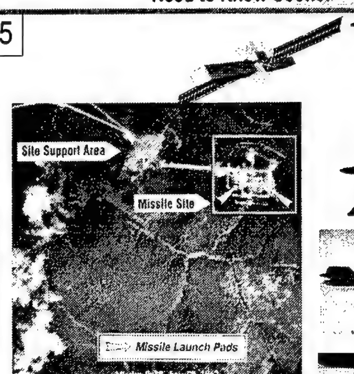
...I conceded that **more intelligence** about their war-making capabilities **was a necessity**."

- President Dwight D. Eisenhower

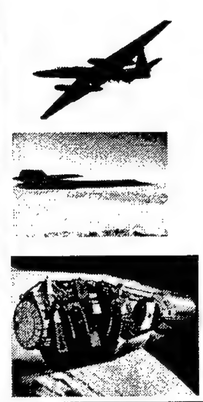
Post - Attack Preparation | **"Need to Know Sooner"**

1950 | 1955 | 1960

"Mummy, what happens to us if the bomb drops?"



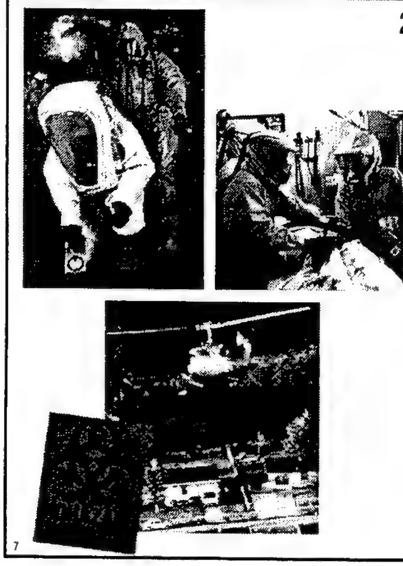
Yurya ICBM Complex of a SS-7 Launch Site (Mission 9038, June 28, 1962)

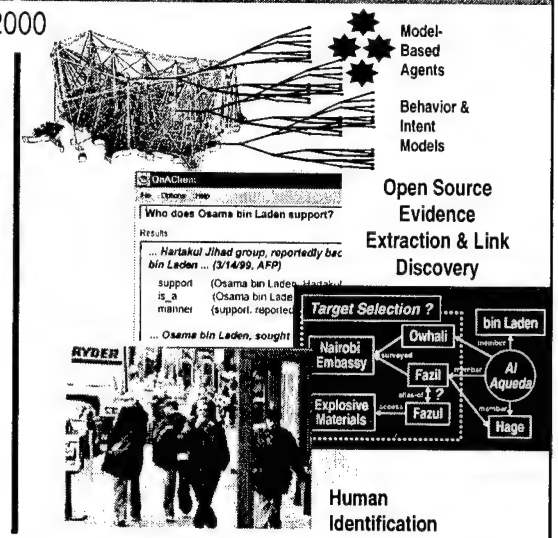


The Asymmetric Threat
Today's Perspective

Post - Attack Preparation | Preemptive: "Need to Know Sooner"

2000

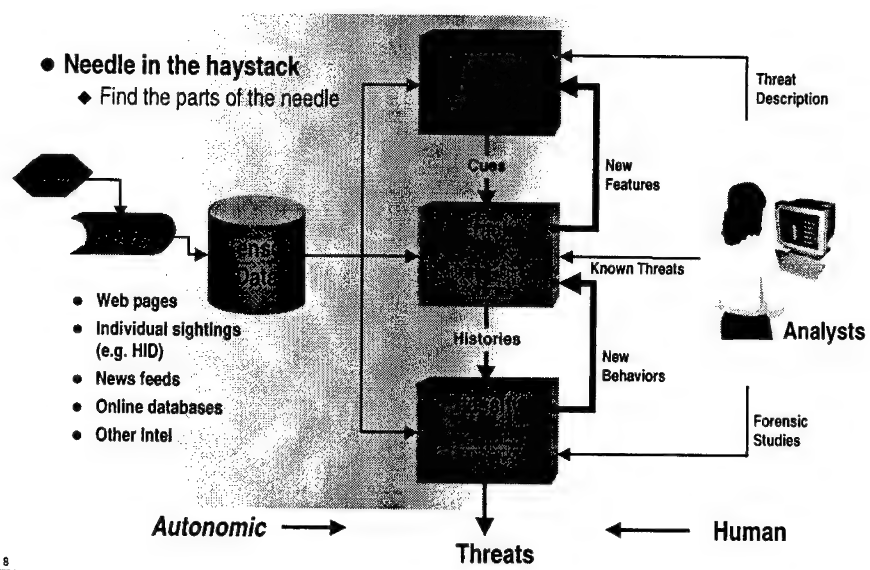




7

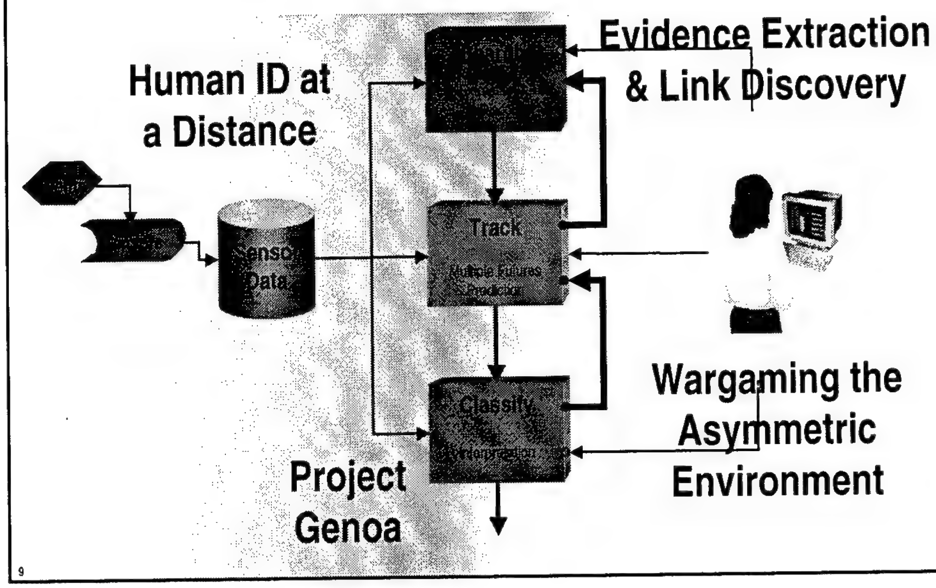
Asymmetric Threat
A Surveillance Problem

- Needle in the haystack
  - Find the parts of the needle



8

Asymmetric Threat Programs



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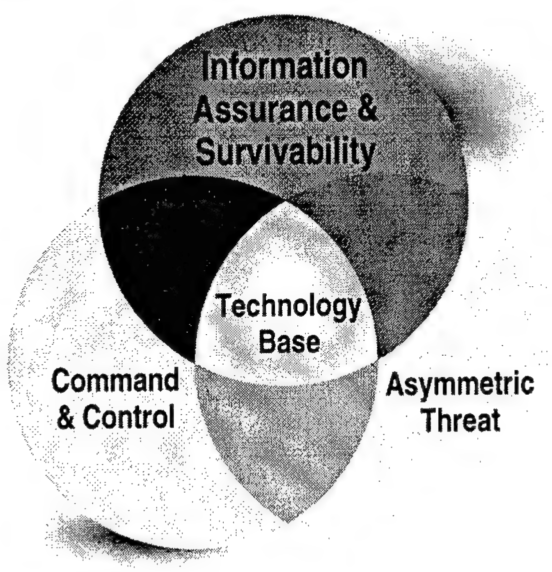
ISO Program Areas



Mitigate national and defense computing infrastructure vulnerabilities that could be exploited by information warfare enemies

10

IA&S Community

Policy

National Security Telecommunications and Information Systems Security Committee

IRC

National Institute of Standards and Technology NIST

President's Commission on Critical Infrastructure Protection

Computer System Security and Privacy Advisory Board

Office of Information Security

C3I

Information Assurance Outreach Program

Forensics & Ops

Services Infosec

FEDERAL BUREAU OF INVESTIGATION
NATIONAL COMPUTER CRIME SQUAD

Defense Security Service

NASIRC

FedCIRC

CIAC

U.S. Department of Energy

NIPC

NIST National Institute of Standards and Technology

N I A P

Research

DARPA

Information Assurance & Survivability
Problem Space

The Problem:

- Our current DOD information security strategy is failing to keep pace with the current threats.
- We anticipate that future threats will be more sophisticated and widespread.

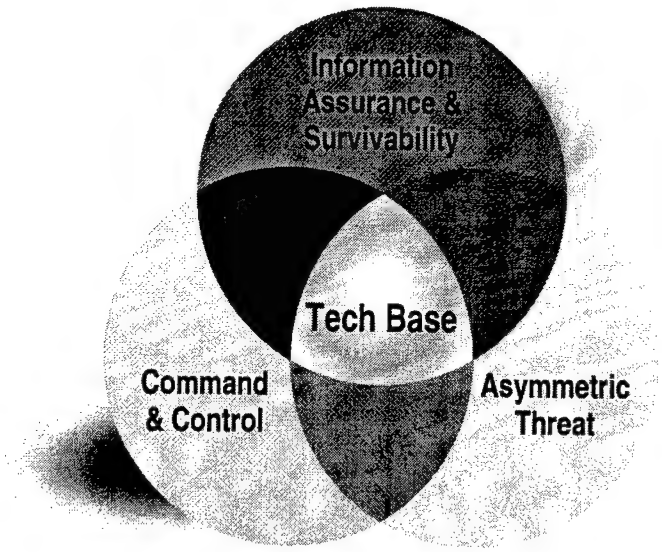
IA&S Responses

- Change the "business model"
  - Operationally focused, system oriented
  - Transfer technology directly to DoD systems
  - Let commercial systems catch up to military-level security
- A broadening of our view of "solution space"
  - Host-based/software approach
  - Include communications and computer architectural engineering
- A broadening of operational focus
  - Wireless, mobile
  - Operational challenge problems

FY01 IA&S Themes

- DoD System Focus
- Operational Experimentation
- Security in Mobile, Wireless Domain
- Impact Upon Command and Control
- Next-Generation Secure Systems

ISO Program Areas



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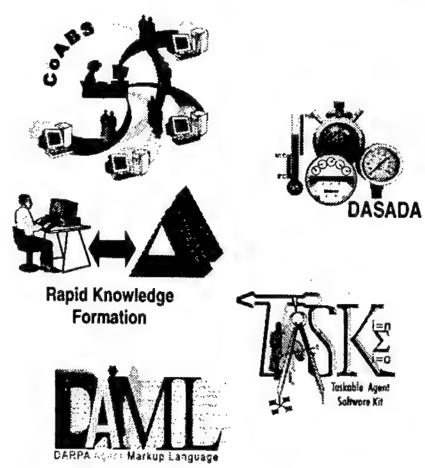
Tech Base:
Supporting ISO, Commercial & DoD Systems

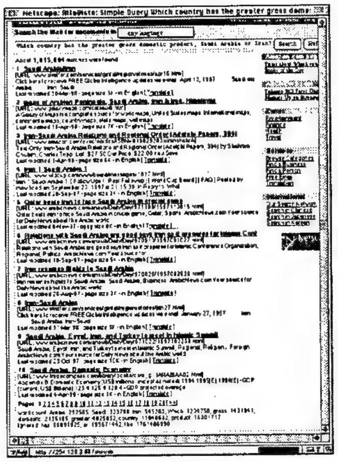


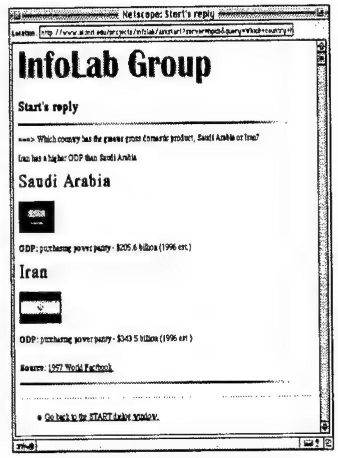
- Agents
- Run time integration of heterogeneous systems
- Reinforcement learning
- Hybrid nonlinear dynamic control
- Mobile agents
- Neural nets
- Scalability
- Interoperability
- Agent clusters and interactions
- Knowledge bases
- System science
- Dynamic assembly of software

16

Knowledge-Based Information Retrieval

Which country has the greater gross domestic product: Saudi Arabia or Iran?



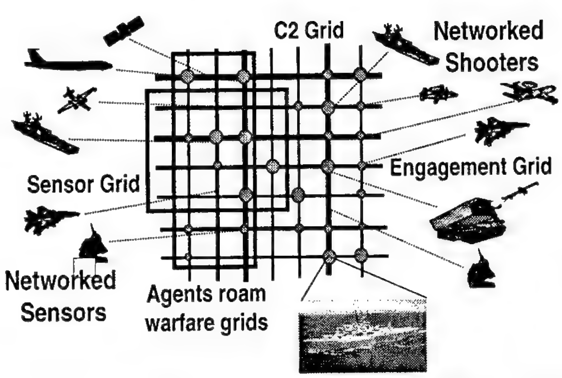


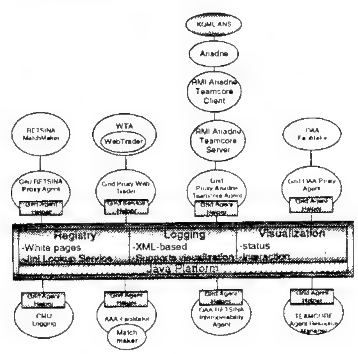
Altavista: 1M responses, first 10 (at least) irrelevant

START (An HPKB Technology): Retrieved just the right information

17

CoABS Grid: *Multi-Agent System Interoperability*



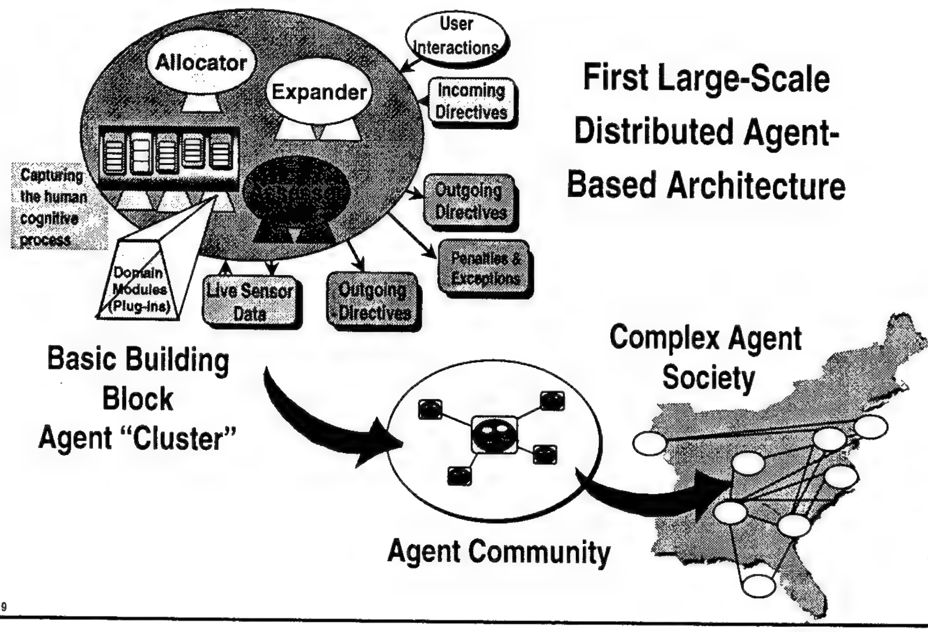


Navy Experiment: Cooperative Agents for Specific Tasks (CAST)

- **Facilitates interoperability of diverse systems**
  - Enables dynamic connection of disparate information sources and C2 applications
  - Enables software systems to cooperatively solve user tasks
- **Grid Agent Helper and the Grid Service Helper facilitate CoABS component access to Grid services and to other registered Grid components**

18

Cognitive Agent Architecture



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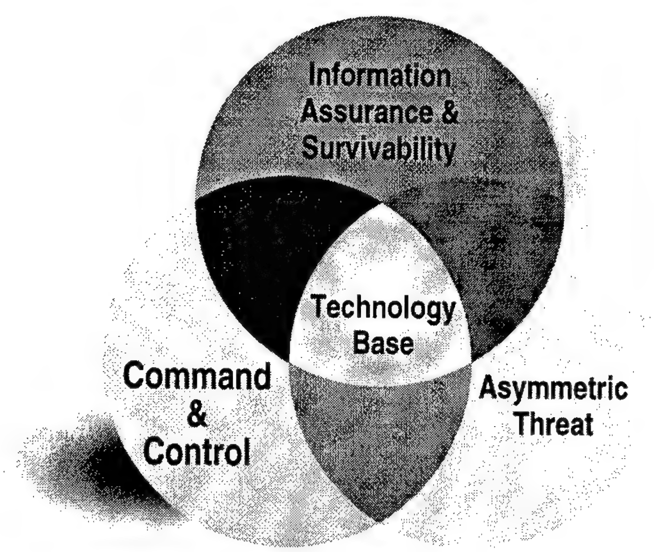
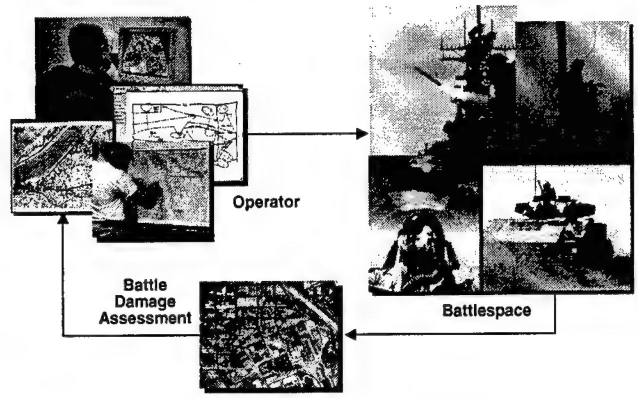
ISO Program Areas



20

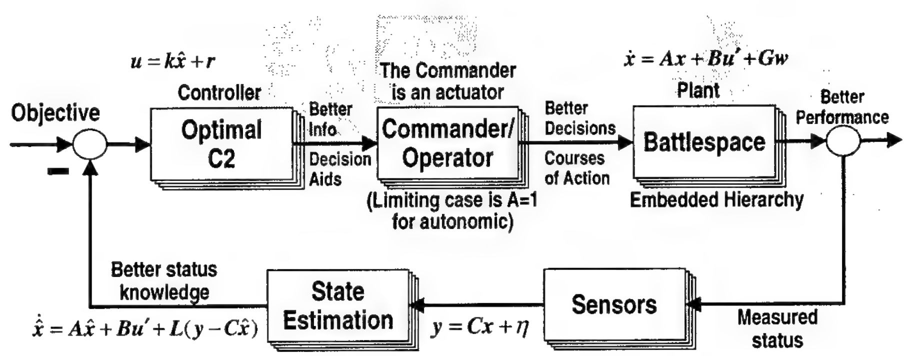
Current Command & Control Limitations

Limitations Today
- Operator reaction limited
- Feedback loop is not coordinated
- Unsynchronized
  - Things start to break
- OODA loop broken e.g., Kosovo



The Future
- Autonomic systems
- Higher op tempo
- Synchronized ops
- Human becomes more of a limitation

Dynamic Control Concept
Man & Machines



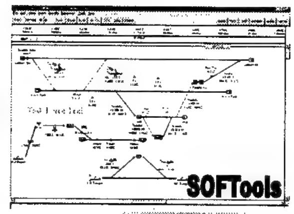
Canonical Structure

Synchronization of manned & autonomic forces in space, time, and purpose can be achieved through the application and extension of control theory

Command & Control Programs

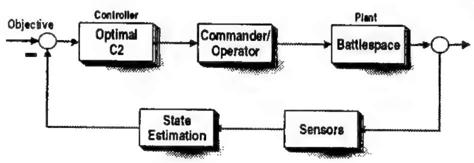
CPOF
Command Post of the Future

Active Templates



Advanced Logistics Project

Ultra Log



Man & Machine Command & Control

Joint Logistics & Joint Theater Logistics ACTDs

23

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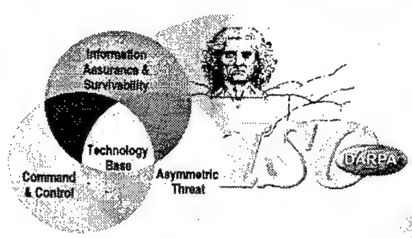
Today's Speakers



Information Assurance & Survivability
Brian Witten

Technology Base
John Salasin - DASADA
Jim Hendler - Agents

Command & Control
Todd Carrico - Ultra Log

Asymmetric Threat
Tom Armour

24

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Information Assurance & Survivability

Brian Witten
Information Systems Office

1

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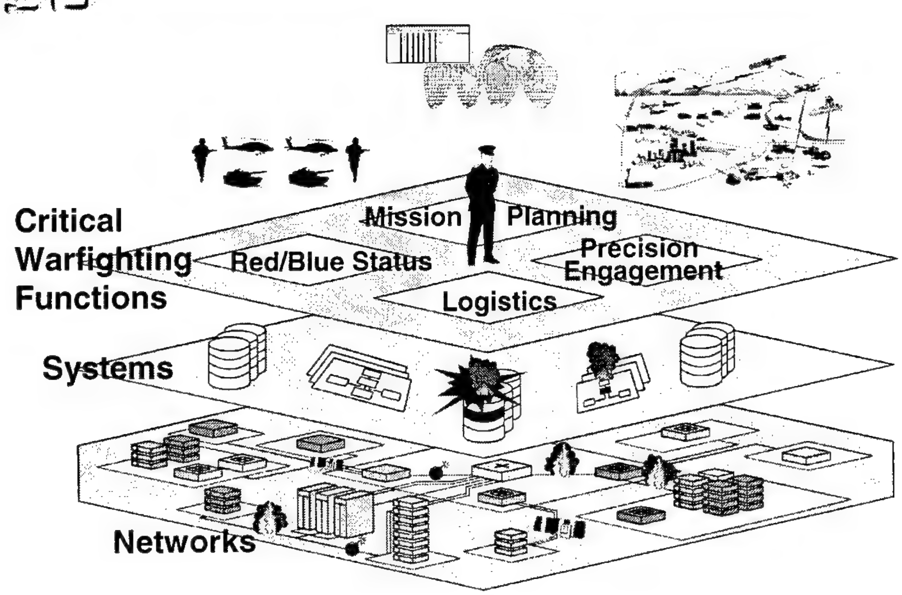
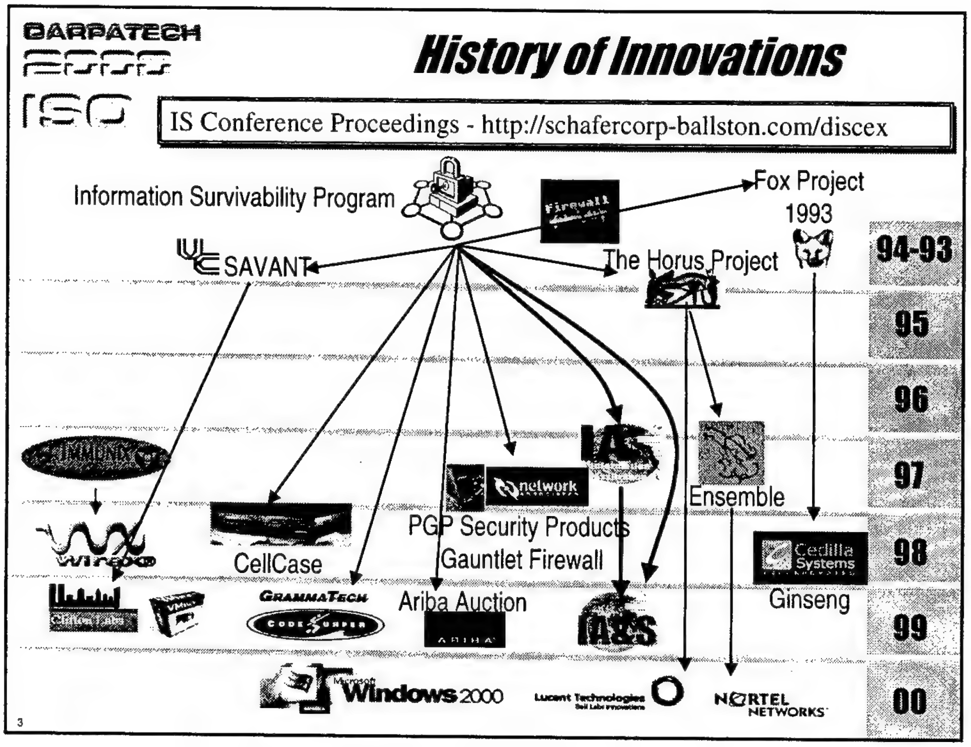
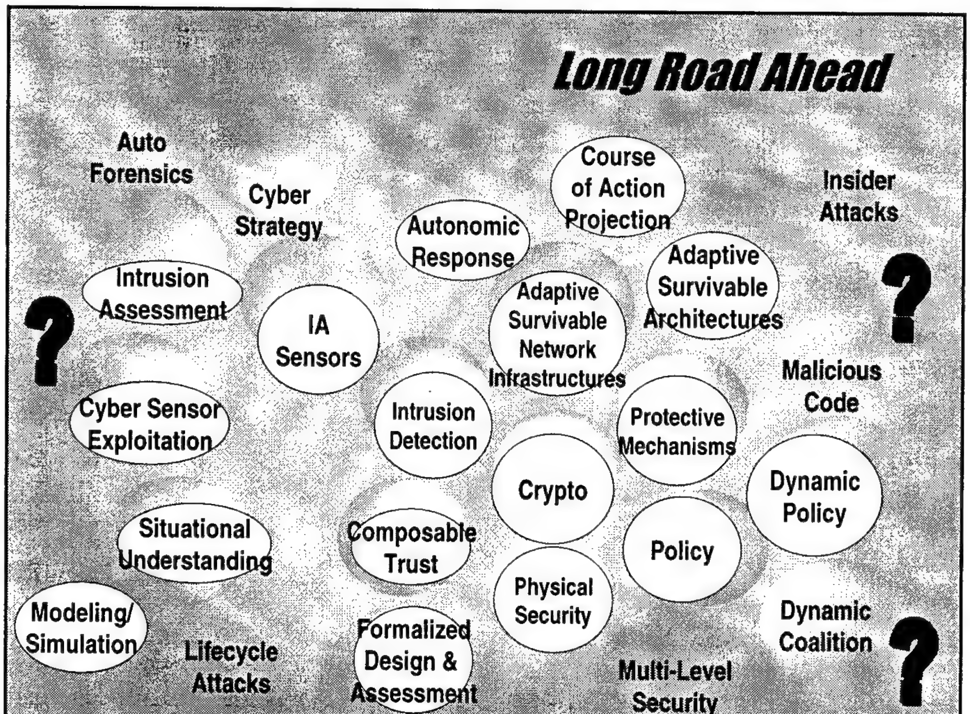
Can we trust the data we are fighting on?



2


DARPATECH 2000
ISO
History of Innovations
IS Conference Proceedings - http://schafercorp-ballston.com/discex
Information Survivability Program
Fox Project
1993
SAVANT
The Horus Project
94-93
95
96
97
98
99
00
Ensemble
PGP Security Products
Gauntlet Firewall
CellCase
Ariba Auction
Ginseng
Windows 2000
NORTEL NETWORKS
3


Long Road Ahead
Auto Forensics
Cyber Strategy
Course of Action Projection
Insider Attacks
Autonomic Response
Adaptive Survivable Architectures
Intrusion Assessment
IA Sensors
Adaptive Survivable Network Infrastructures
Malicious Code
Cyber Sensor Exploitation
Intrusion Detection
Protective Mechanisms
Crypto
Dynamic Policy
Situational Understanding
Composable Trust
Policy
Physical Security
Modeling/ Simulation
Lifecycle Attacks
Formalized Design & Assessment
Multi-Level Security
Dynamic Coalition
?
?
?

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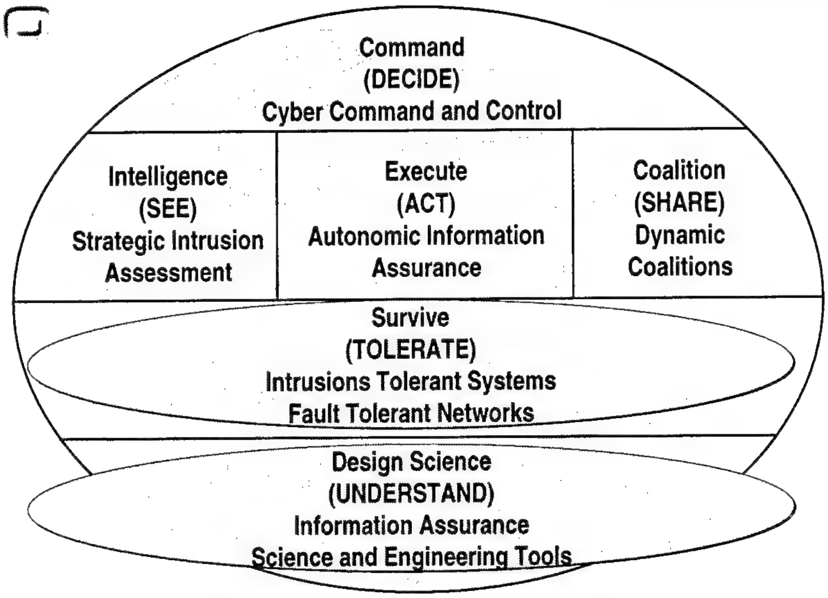
Objectives



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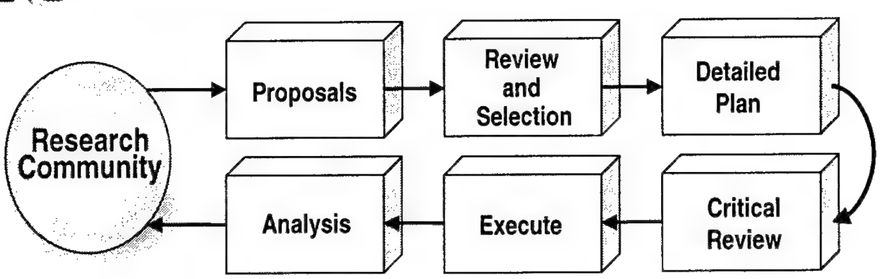
Approach: Scientific Experimentation



Grand Hypotheses:

- Layered Defense
- Dynamic Defense
- Assurance Methodology
- Automated Response
- Automated Decision Support

Types of Experiments:

- Field Experiments
- Red Team Lab Exercise
- Laboratory Experiments
- Interdisciplinary White-Boarding
- Component Specific Testing

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Contact

Autonomic Information Assurance............. Brian Witten
Dynamic response — bwitten@darpa.mil

Cyber Command & Control.......... Catherine McCollum
Human directed strategy — cmccollum@darpa.mil

Dynamic Coalitions............................. Doug Maughan
Coalition policy mechanisms — dmaughan@darpa.mil

Fault Tolerant Networks...................... Doug Maughan
Tolerant mechanisms — dmaughan@darpa.mil

IA Science & Engineering Tools............. Michael Skroch
Design tools & models — mskroch@darpa.mil

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Tolerant systems — jlala@darpa.mil

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Attack recognition & correlation — cmccollum@darpa.mil

Cyber Sensor Grid......................... Catherine McCollum

Malicious Code Mitigation....................... Michael Skroch

Reliable Mobile Agents.................................. Brian Witten

Secure Operating Systems........................ Doug Maughan

Security of High Speed Networks............... Doug Maughan

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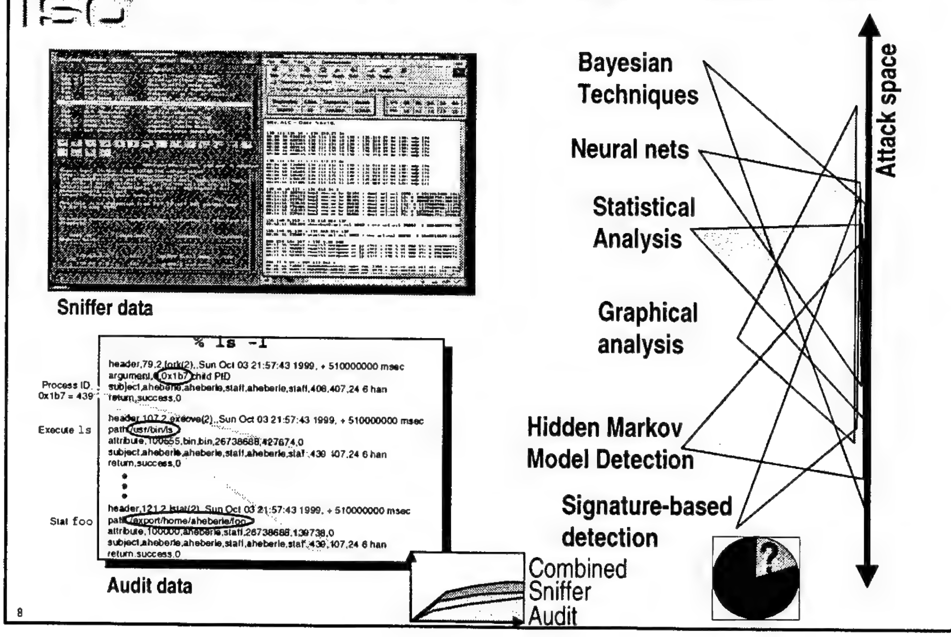
New Focus: Cyber Sensor Grid



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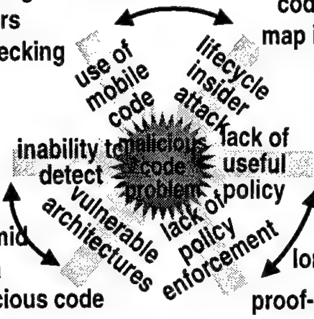
New Focus: Malicious Code Mitigation

problem-defining
primarily
program-external



sandboxing
wrappers
integrity checking

~~cleared developers~~
code signing standard
map insider effects to MC

static code analysis
code authentication
anomaly detection
epidemiological-based

policy management tools
checking tools
policy composition

short-mid term:
theories for malicious code
tolerant architectures
bilateral trustworthy path
static & adaptive fault tolerance

long-term:
proof-carrying code
theory of response

Complicating factors:
- More COTS
- Increasing use and reliance on systems
- Increasing connectivity

Strategy:
- Detect & Expunge "On the Fly"
- New Architectural Concepts
- Address Policy Language Lag

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New Focus: Reliable Mobile Agents

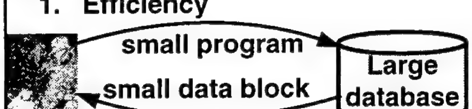
Mobile Agents are:

Programs that can migrate from machine to machine under their own control.

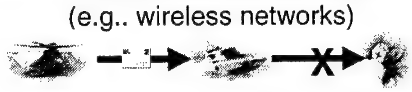
Code mobility...

Functionally enhances:

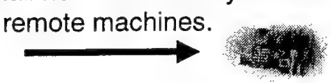
1. **Efficiency**



2. **Disconnected operations**
(e.g.. wireless networks)

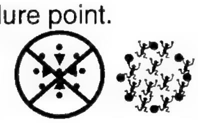


3. **Flexibility**
Install new functionality on remote machines.



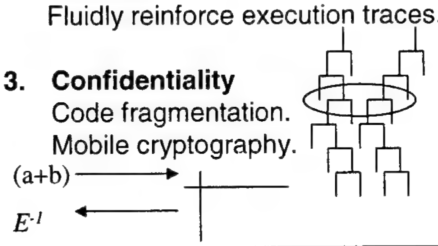
Presents Survivability Opportunities:

1. **Availability**
No central failure point.



2. **Integrity**
Fluidly reinforce execution traces.

3. **Confidentiality**
Code fragmentation.
Mobile cryptography.



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Conclusions:

- National Level Problem
- DARPA "high-risk"/ "high-reward" focus

New Focus Areas:

- Cyber Sensor Grid
- Malicious Code Mitigation
- Reliable Mobile Agents

Proven Success:

- ARPANET
- Firewall Toolkit

Waiting Gold:

- Secure Domain Name Service
- Internet Protocol Security (IPSEC)
- Secure Border Gateway Protocol
- Next Generation Intrusion Detection

More to Come:

- Denying Denial-of-Service
- Self-Healing Systems
- Proof Carrying Code
- Trace Back
- Dynamic Defense
- Metrics & Science Based Design

IA&S Information – www.darpa.mil

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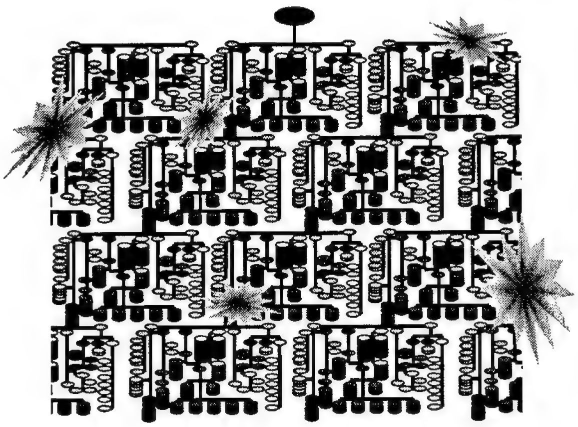
ULTRA*LOG



Large-Scale, Robust, Secure Agent Technology for Today's Chaotic Wartime Environments

Todd M. Carrico
Information Systems Office

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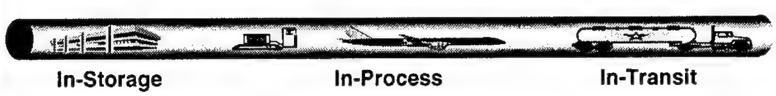
ALP: Achieving Focused Logistics

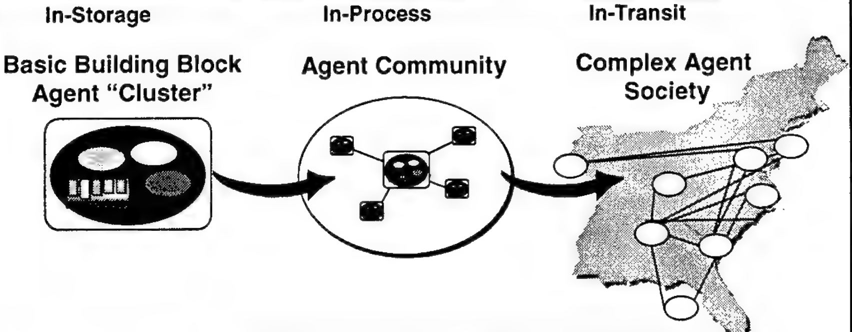
Objective

Getting Control of the Logistics Pipeline...

- Planning, Managing, and Providing Visibility
- All Echelons, All Phases of Operations
- Continuous Planning and Execution

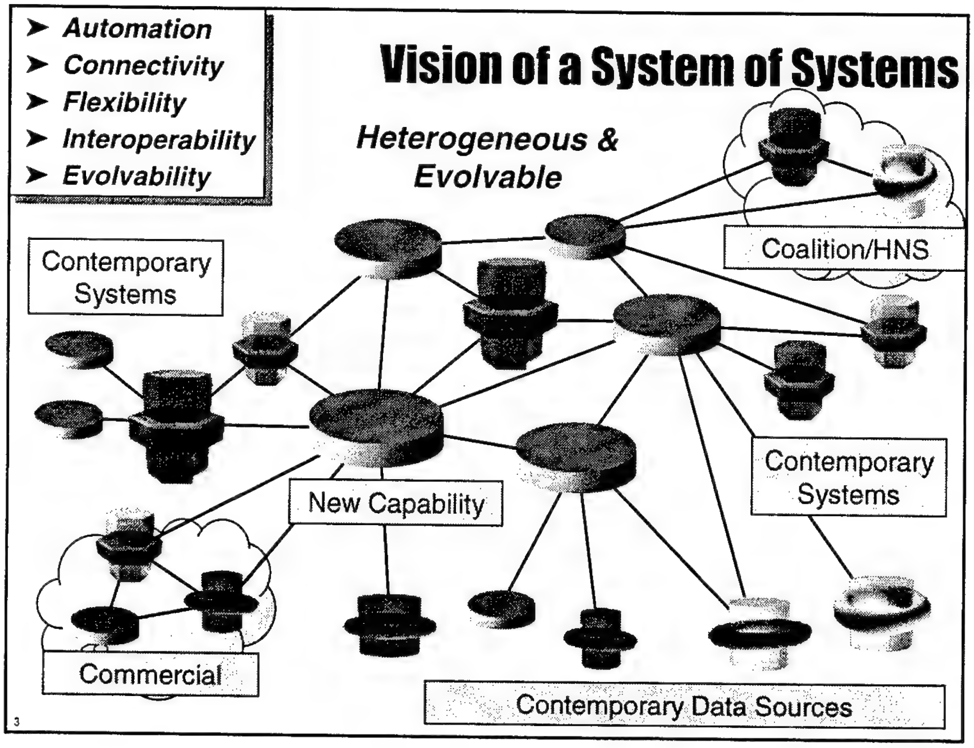


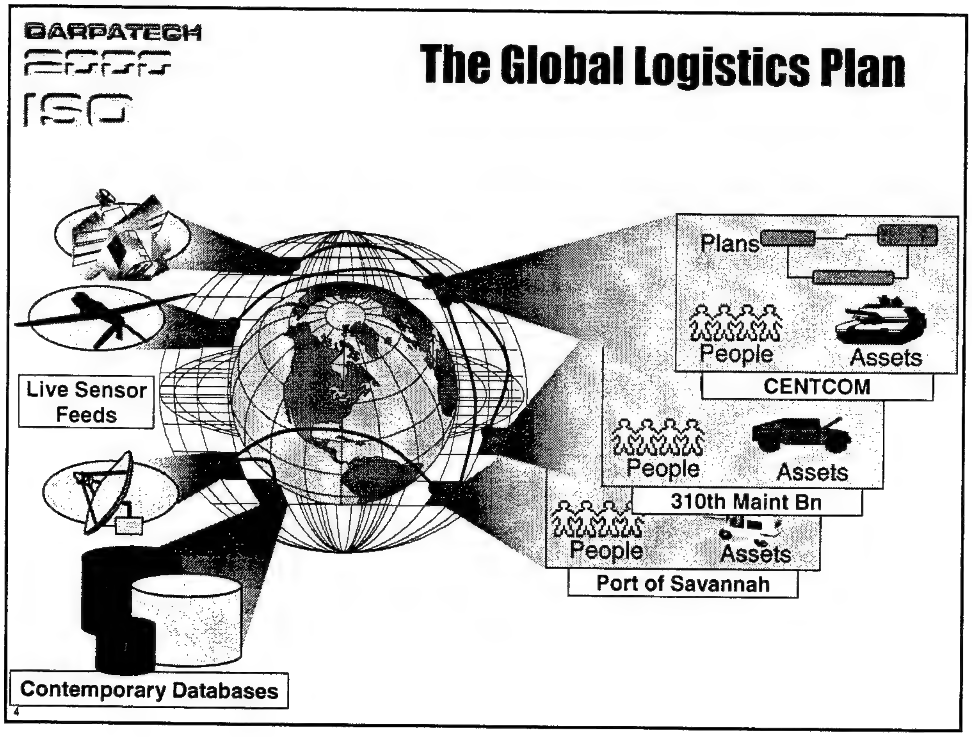
Approach



First Large-Scale Distributed Agent-Based Architecture

2


➤ Automation
➤ Connectivity
➤ Flexibility
➤ Interoperability
➤ Evolvability
Vision of a System of Systems
Heterogeneous & Evolvable
Coalition/HNS
Contemporary Systems
New Capability
Contemporary Systems
Commercial
Contemporary Data Sources
3


DARPATECH
The Global Logistics Plan
Live Sensor Feeds
Contemporary Databases
Plans
People
Assets
CENTCOM
People
Assets
310th Maint Bn
People
Assets
Port of Savannah
4

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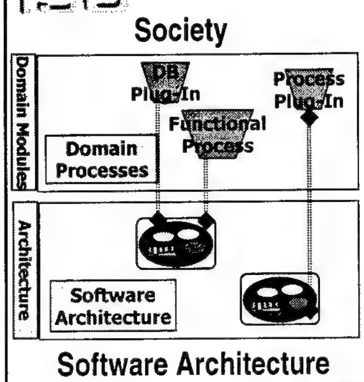
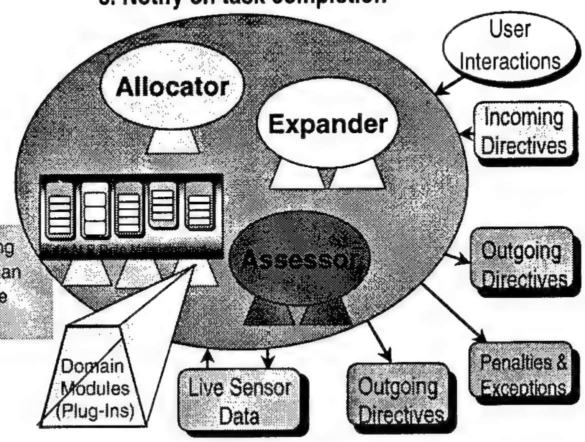
Cognitive Agent Architecture

1. Receive tasking
2. Decompose task into doable subtasks
3. Complete subtask or assign to subordinate
4. Monitor execution, replan as required
5. Periodically report status
6. Notify on task completion





5

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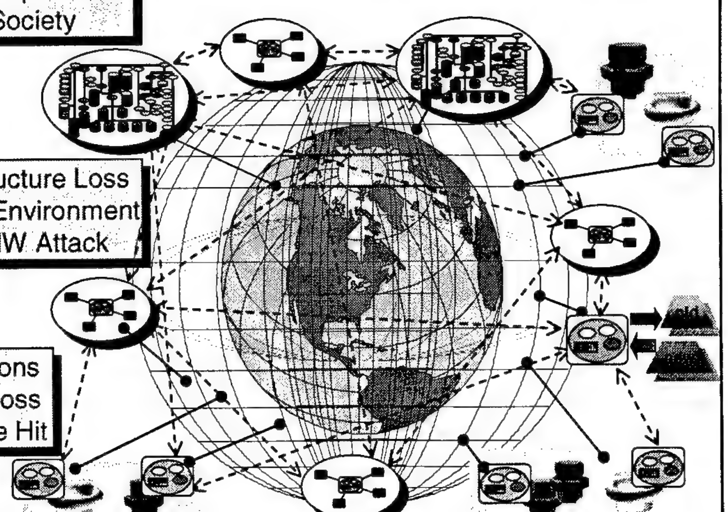
The Ultra*Log Challenge

Major Region Contingency
180 Days of Global Operations
> 1000 Agent Society

Up to 45% Infrastructure Loss
Extremely Chaotic Environment
Directed Enemy IW Attack

Survivable Operations
< 20% Capability Loss
< 30% Performance Hit



6

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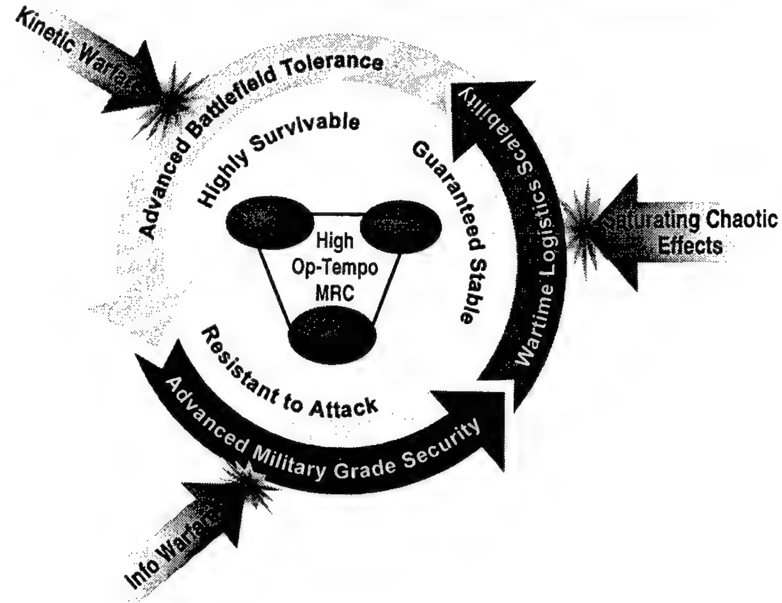
The Operational Concept



7

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Extending the Cognitive Agent Architecture

	Currently under ALP	Future with Ultra*Log
Robustness	**Basic Fault Tolerance** ➢ Localized persistence of state ➢ Stable under intermittent comms ➢ Run-time manual reconfiguring	**Adv Battlefield Grade Tolerance** ➢ Dynamic comms-aware redundancy ➢ Catastrophic fault isolation / recovery ➢ Dynamic adaptation to environment ***Highly Survivable***
Security	**Std Commercial Grade Security** ➢ Signed JARS, applets, config files ➢ PKI certifications ➢ Inter-community VPNs	**Advanced Military Grade Security** ➢ Multi-layered, mode resistant security ➢ Assured, adaptive availability ➢ Assured data integrity / pedigree ***Resistant to IW Attack***
Scalability / Stability	**Peacetime Logistics Scalability** ➢ Time-phased locality of information ➢ Efficient simple negotiations ➢ Rich encapsulation of functionality ➢ Optimized task grammar / data model	**Wartime Logistics Scalability** ➢ Streamlined / compressed negotiation ➢ Variable fidelity adaptive processes ➢ Resource pooling / Mode mgmt ***Guaranteed Stable***
Project Objective	**Large-Scale Distributed Agent Architecture for Logistics**	**Integrated System Solution for Agent Societies operating in Intense IW Environment**

8

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Conclusion

- The Ultra*Log BAA is out (www.darpa.mil)
- The first-round of proposals are coming in
- The BAA will be open for another year
- Want maximum participation from all sectors
- Seeking leading-edge technologies in security, robustness and scalability
- Goal is to enhance the COUGAAR (Cognitive Agent Architecture: www.cougaar.org) technology so it can support a massive-scale, trusted, distributed agent infrastructure for logistics

Asymmetric Threat Initiative

Tom Armour
Information Systems Office

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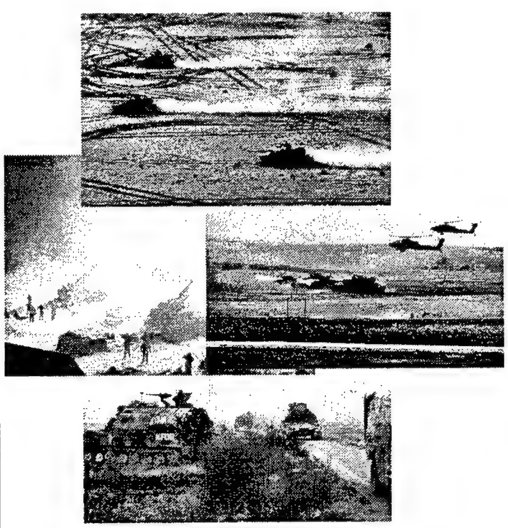
Threat Development and Detection
Then **& Now**

Conventional



Asymmetric

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Asymmetric Threat Projects

- Human Identification at a Distance
- Evidence Extraction and Link Discovery
- Wargaming the Asymmetric Environment
- Project Genoa
- Rapid Knowledge Formation
- Agent-Based Computing

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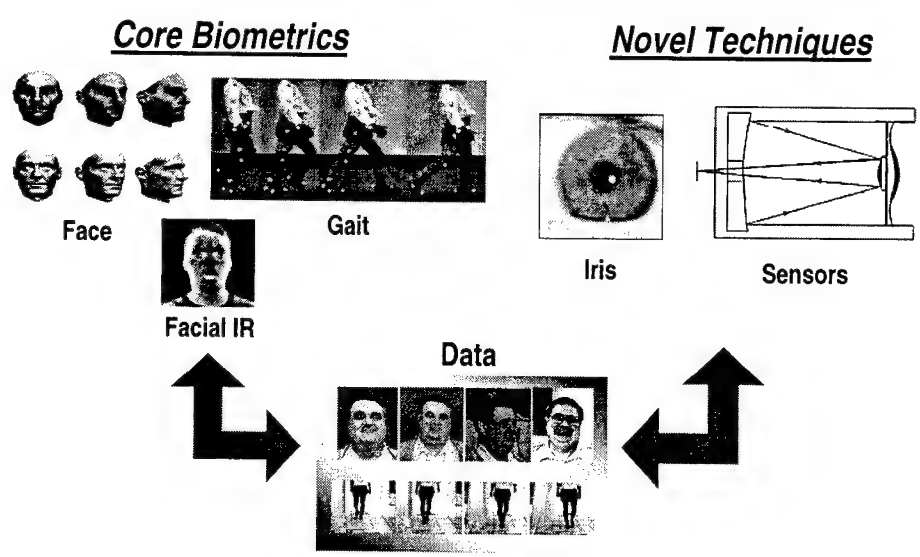
Human Identification at a Distance (HumanID)



Asymmetric Threat Projects

- Human Identification at a Distance
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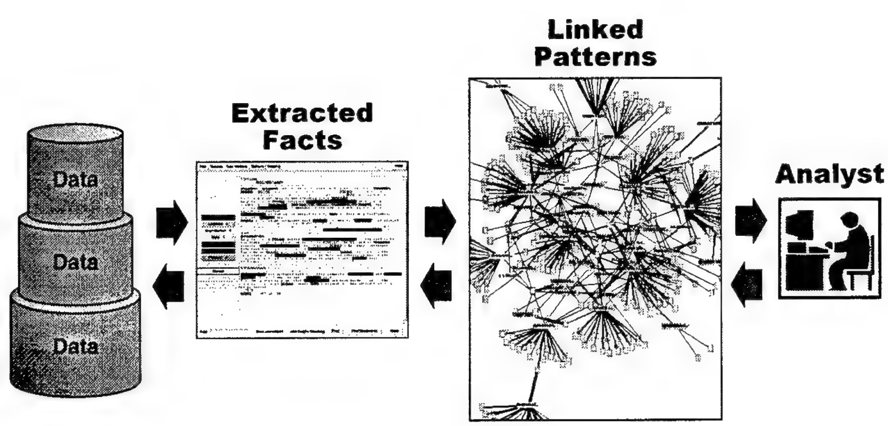
- Wargaming the Asymmetric Environment
- Project Genoa
- Rapid Knowledge Formation
- Agent-Based Computing

5

Evidence Extraction and Link Discovery



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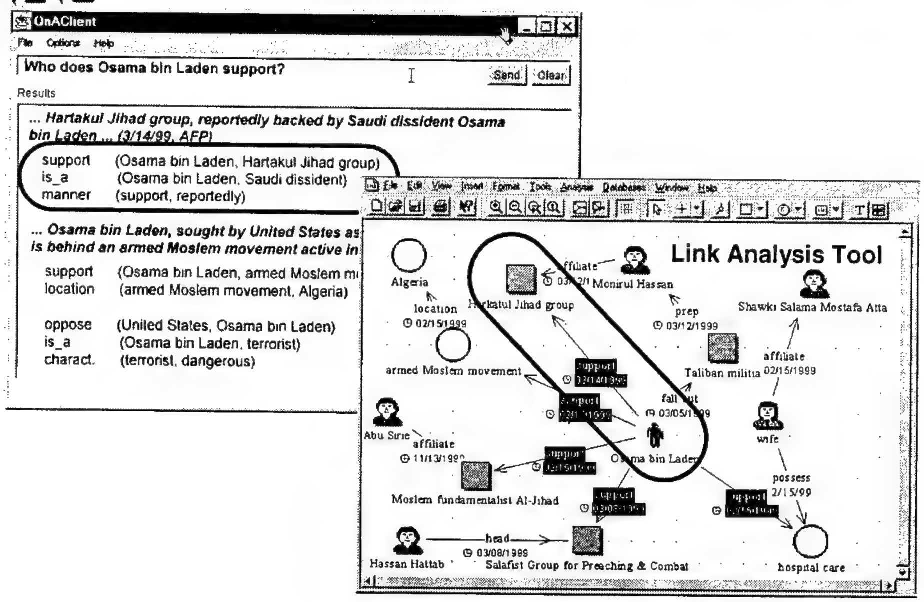
Evidence Extraction for Link Discovery
Step 1: Extracting Relational Facts



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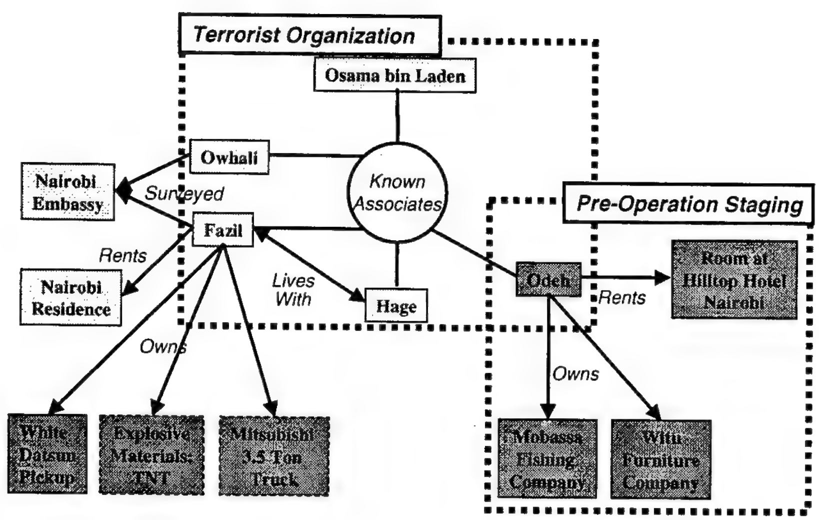
Evidence Extraction and Link Discovery
Step 2: Recognizing Relational Patterns



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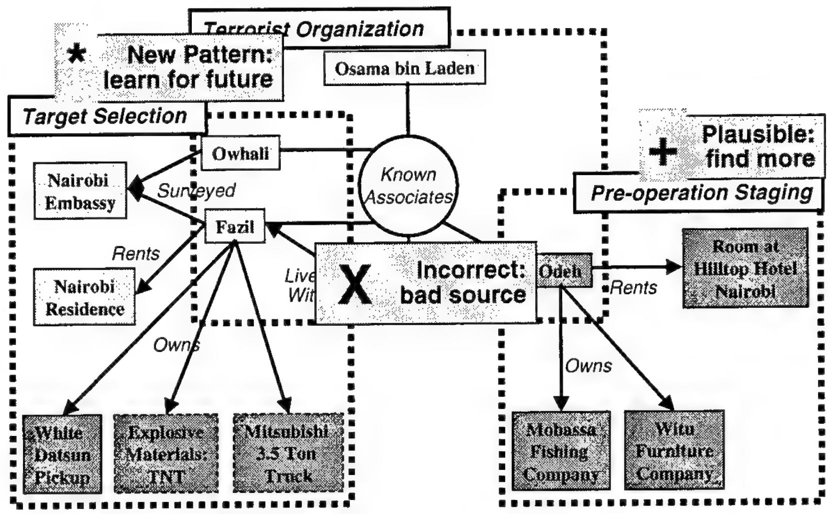
Evidence Extraction and Link Discovery
Step 3: Analyst's Feedback



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Asymmetric Threat Projects

- Human Identification at a Distance
- Evidence Extraction and Link Discovery
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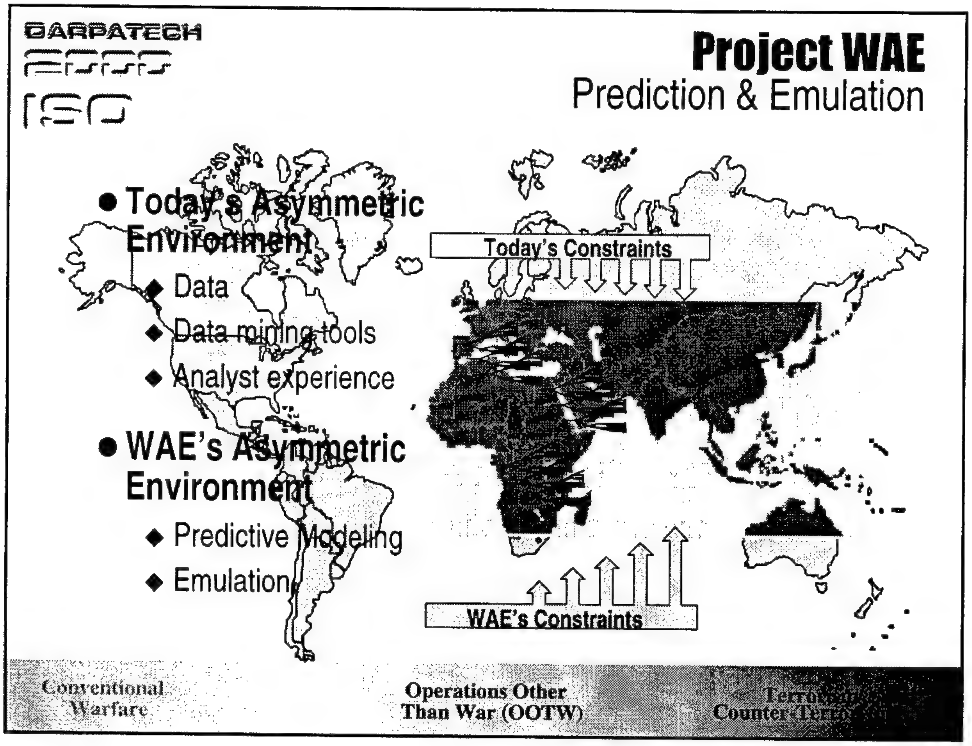
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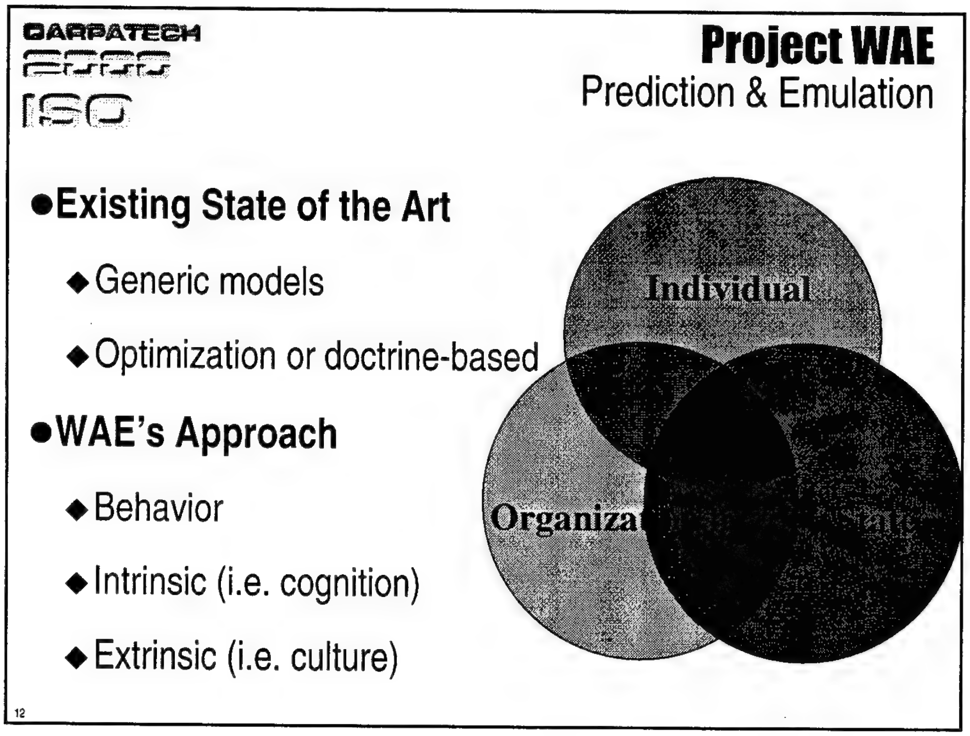
2000
ISO
Project WAE
Prediction & Emulation
● Today's Asymmetric Environment
◆ Data
◆ Data mining tools
◆ Analyst experience
● WAE's Asymmetric Environment
◆ Predictive Modeling
◆ Emulation
Today's Constraints
WAE's Constraints
Conventional Warfare
Operations Other Than War (OOTW)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ISO
Project WAE
Prediction & Emulation
●Existing State of the Art
◆Generic models
◆Optimization or doctrine-based
●WAE's Approach
◆Behavior
◆Intrinsic (i.e. cognition)
◆Extrinsic (i.e. culture)
Individual
12

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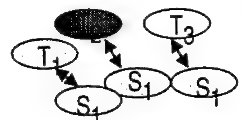
Project WAE

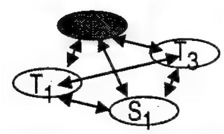
Prediction & Emulation

- **Existing State of the Art**
  - ◆ Sequential opponents
  - ◆ Cumulative Error
- **Technology Areas Of Interest**
  - ◆ Multi-dimensional games
  - ◆ Non-zero sum game
  - ◆ Valuated state space for qualitative data

Two very different results



Sequential



Multi-dimensional

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Upcoming BAA's

- **Evidence Extraction and Link Discovery**
  - ◆ Expected in the Fall of 2000
- **Wargaming the Asymmetric Environment**
  - ◆ Expected in the Fall of 2000

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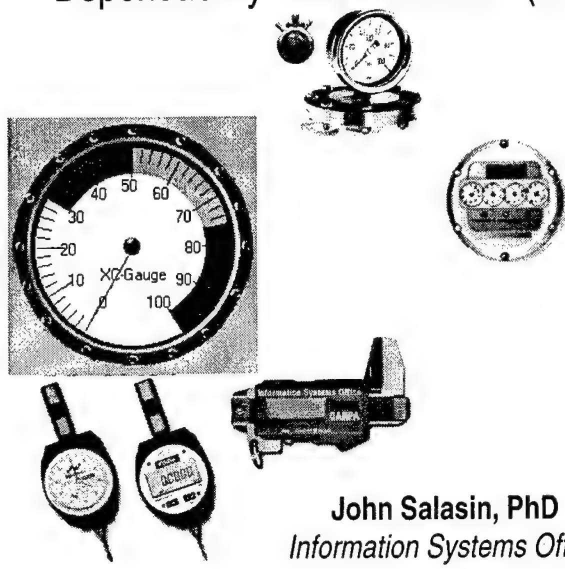
Dynamic Assembly for System Adaptability, Dependability and Assurance (DASADA)

The software revolution requires dynamic gauges



But gauges made it happen

And an ability to dynamically update and use models

John Salasin, PhD

Information Systems Office

DARPA

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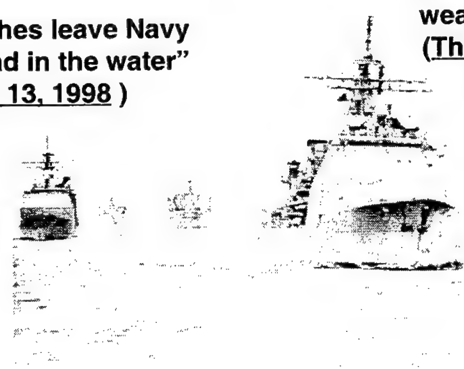
Problem

"Software glitches leave Navy Smart Ship dead in the water"
(GCN July 13, 1998)

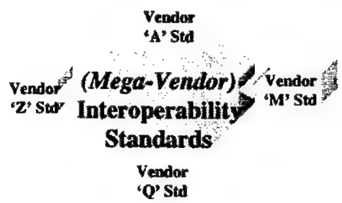
"Glitch in combat systems software knocks out weapons capability"
(The Virginian-Pilot, July 8, 1998)



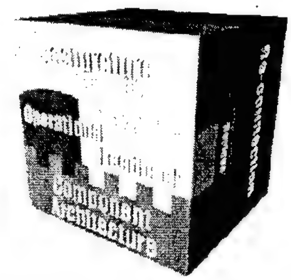
We can't completely model today's complex systems. Therefore, we can't: Understand them; Predict them; Control them; Automatically compose or adapt them.

Why DASADA

Industry hasn't done it, DoD needs it



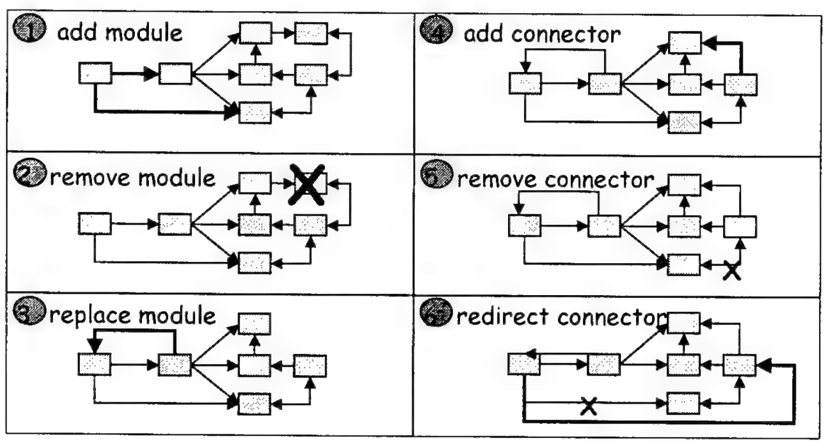
Software Fix(s), re-connector(s), glue and gauges



Predictable composition is key to reduced cycle time

- Dynamically assemble, reconfigure, and evolve systems
- Easily introduce new components to add functionality
- Adaptively and dynamically scale systems
- Continuously upgrade components

Transformation Based Architecture



Assess suitability before, during, and after architecture transformations

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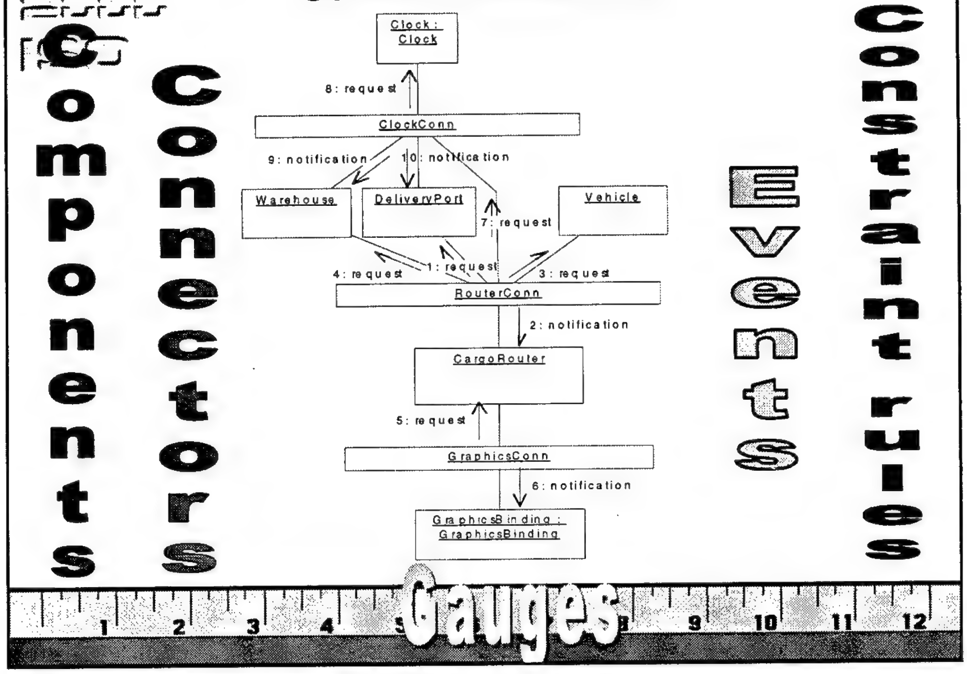
Software Architecture



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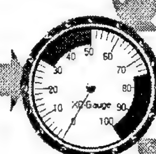
Gauges Are Central

Gauges assess suitability before, during, and after software architecture transformations.

Continual Coordination

- **Architecture Conformance**
- **Composability Wrapper**

Connectivity



Continual Design

- **Functional Similarity**
- **Content Similarity**

Example: Constraint-based Gauge

Continual Validation

Evolution and Integration Command Center

- **Runtime Event Monitoring**
- **Connectivity Gauges**

Automatic, dynamic (re)configuration is a key element of the DASADA software vision.

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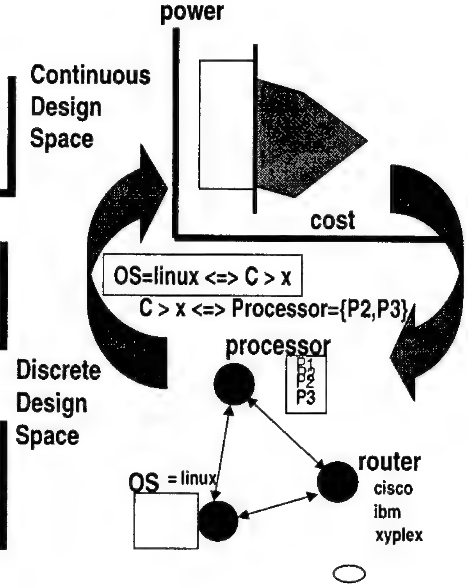
Constraint Gauges

Goals — Verify system architecture

Method — Incremental invocation of constraint based gauges

Technical Basis — Formal definition of system level gauges



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Connectivity Gauges

Goals

- Determine runtime component
- Determine how connections were made

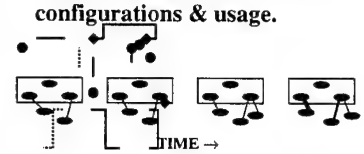
Method

- Insert gauges at a variety of probe points
- Monitor creation and change of component bindings
- Monitor flow of requests

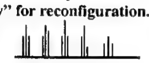
Technical Basis

- Ubiquitously insert runtime gauges into component-based applications

Determining actual runtime configurations & usage.



Monitoring interaction patterns to determine "windows of opportunity" for reconfiguration.



ACTIVITY vs. TIME

Detecting "dead code" that increases code footprint, may harbor viruses, and complicates evolution & testing. The gauge may provide the following advice:

"The MathPak library is bound to your application, but has not been used for 3 months by any user of your application. The library may represent dead code. Library size is 5MB. The library was bound to your application by the gLinker tool on 12/13/99 using the file myMake."

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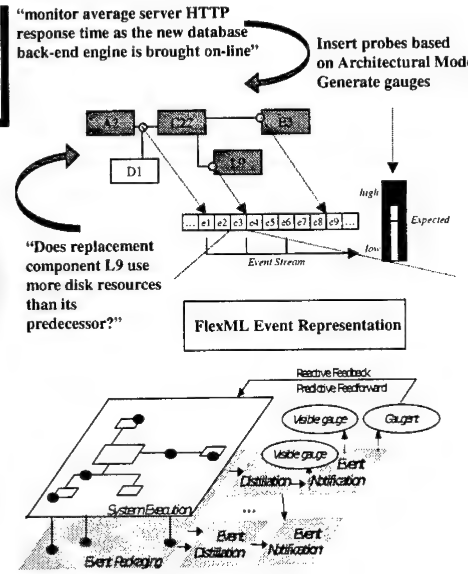
Gauge Infrastructure: Evolution and Integration Command Center

Goal
- Enable "go/no-go" decision for re-configuration tasks
- •Monitor "live" evolution of systems

Method
- •Rapid hypothesis testing
- •FlexML event description
- •Dynamic probing of components

Technical Basis
- •Architectural models show how to develop testing regiment



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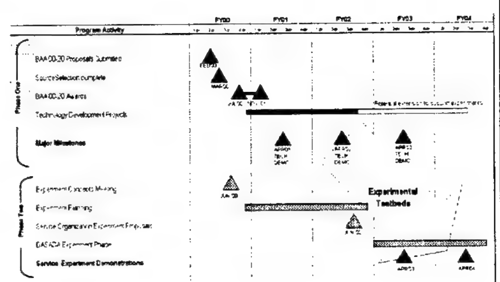
DASADA Phase 2: New Opportunities:Transition Technology to Experiments

GUARANTEE CRITICAL PROPERTIES

REDUCE TIME TO INTEGRATE

INCREASE ASSURANCE EFFICIENCY



Phase 2 Plans
- (Partially) funded planning efforts in FY01-02 (estimate $25K/year)
- Experiments conducted in FY03-04 (estimate 2-3 @ $5,000K each)
- Requires application by DoD organization

Looking for programs with:
- Real problems
- Ability to evaluate the impact of the technology(ies)
- Interest and commitment of the Service organization and contractor(s)

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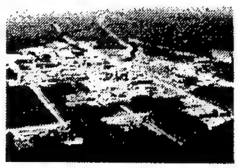
Example Problems for Technology Transition to Experiments

<u>Guarantee Critical Properties</u>

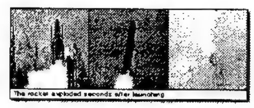
Architectural assessment guarantees critical properties

<u>Reduce Time To Integrate</u>



NEW OPPORTUNITIES

<u>Increase Assurance Efficiency</u>



Models of architecture and behavior reduce integration time/cost.

Update models and axioms based on operational experience

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Action Items

- Watch our progress – at ISO WWW site.
- Think about becoming active in planning an experiment – info at ISO WWW site
- Contact us (jsalasin@darpa.mil)

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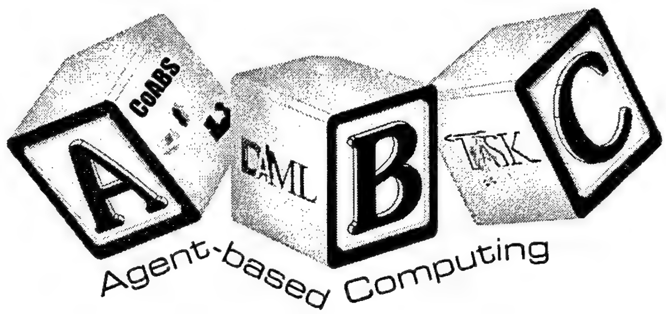
ISO



Jim Hendler
Information Systems Office

1

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ISO

"Agent" **is used for many things...**

Mobile Code

"Intelligent" Interfaces

"Disembodied" Code

Semantic Brokering

Applets

Information Filtering

Negotiation Protocols

Distributed Component Libraries

Information Extraction

Auction Mechanisms

UAV Ops

Dynamic Middleware

Search Tools

Active Messaging

Robots

Mobile Networking

2

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...And the DoD needs all of them!

- **These capabilities map to critical military problems**
  - Asset assignment in real-time <-> e-comm auction mechanisms
  - Bandwidth restrictions <-> active messaging
  - Comm QoS problems <-> mobile code
  - Data visualization <-> interface agents
  - Elint filtering <-> disembodied "monitor" code
  - Field upgradable software <-> applets
  - Gathering open source intelligence <-> Info agents
  - High speed, small unit ops <-> autonomous behaviors
  - Information assurance <-> agent wrappers
  - Joint force & coalition interoperability <-> agent middleware
  - Zero casualty ops <-> UAVs, robots

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Which grow out of the definition of agency

- **An agent is a software component or system that is:**
  - Dynamic in its behaviors (not single I/O mapping)
  - Embedded in, and "aware" of, an environment
  - User enabled/steered, but "empowered" to act for user
  - Able to improve its behavior over time

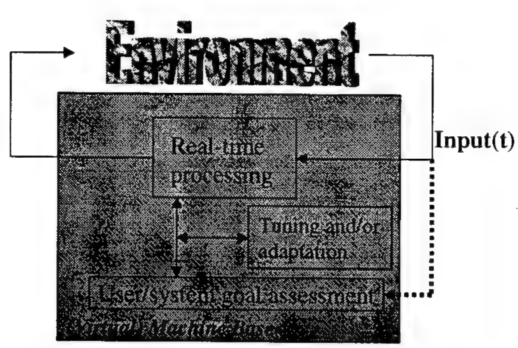
Autonomous

Communicative

Capable

Adaptive

These are important properties for software systems



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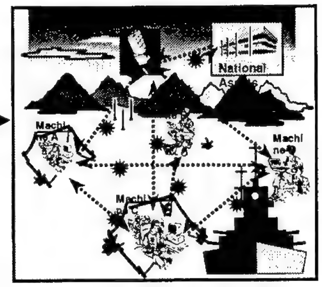
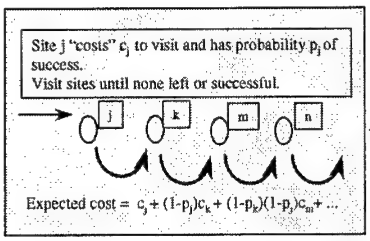
DARPA's ABC programs merge science and practice

- **Military TIEs stress *interoperability***
  - OOTW
    - NEO Challenge Problem
  - Theater Ballistic Missile Defense
    - Used in Fleet Battle Experiments
  - Coalition Force Interoperability
    - DERA/AFRL/DARPA Project underway
  - Others
    - Air Mobility Command, JIATF-E



- **Scientific TIEs stress *scaling***
  - Negotiation Experiments
    - 1st results favor auctions
  - Mathematical Analyses
    - New results for agent mobility
  - Control Scheme Comparison
    - Analysis of time/ Experiments designed



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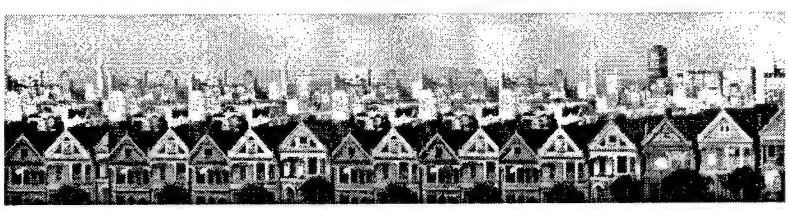
Common Architecture



vs

Heterogeneity

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CoABS Feasibility Demo: Heterogeneous Systems Interoperability Challenge

- 21 different agent systems and services integrated in 2 weeks
  - Distributed development
    - 9+ organizations/sites
  - Six implementation languages
    - Java, Lisp, C++, Prolog, Soar, C
  - Multiple platforms
    - Windows NT, UNIX Solaris
  - Three Agent Communication Languages
    - e.g., OAA ICL, KQML, FIPA ACL

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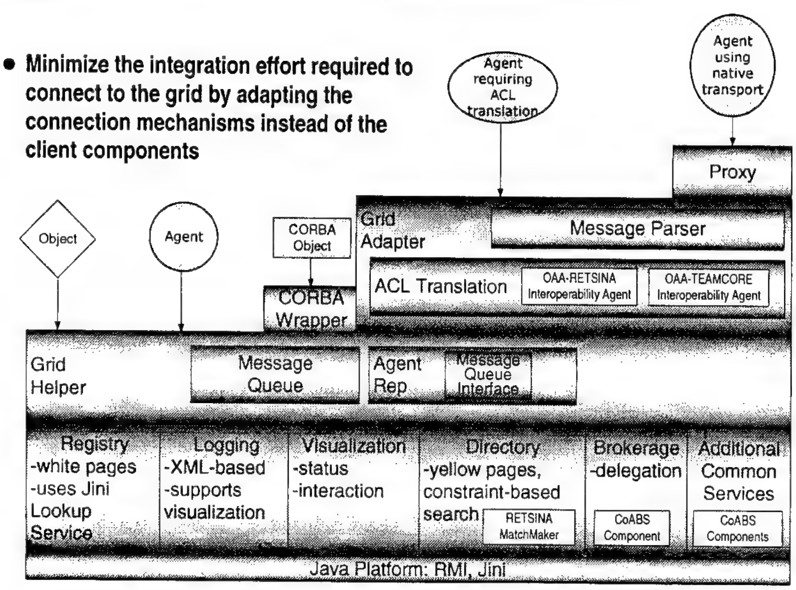
CoABS Grid "Architecture"

- Minimize the integration effort required to connect to the grid by adapting the connection mechanisms instead of the client components



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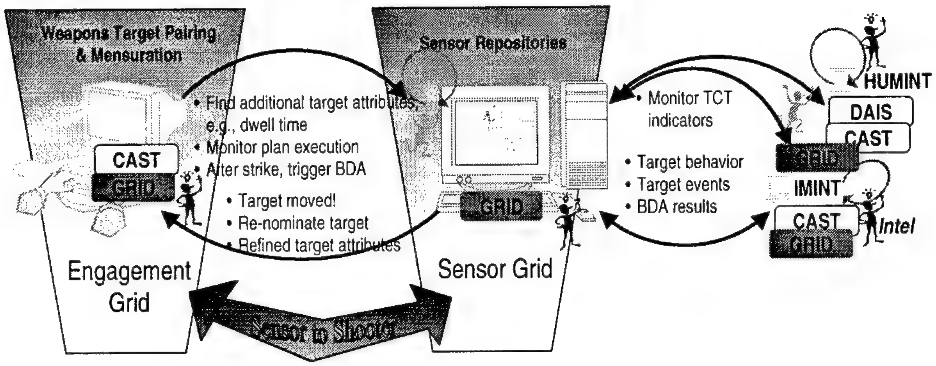
Agents CAST/Grid used in Missile Defense Cell, Fleet Battle Experiment - Foxtrot, Dec 1999



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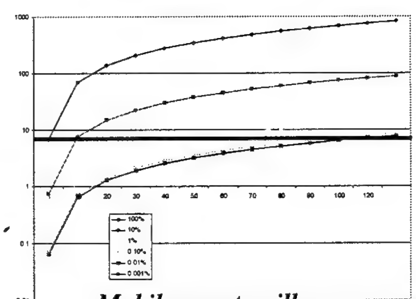
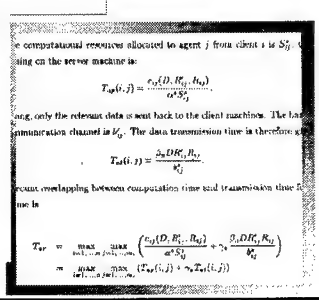
Agents Analysis of Bandwidth Usage



Mobile agents will decrease bandwidth usage. More powerful servers help, not hurt, scaling possibilities when bandwidth limited.



- Analyzed scaling of mobile-agents based on performance parameters from FBE-Echo
- Developed mathematical model of bandwidth trade-offs for mobile-agent vs. broadcast of information (limitation: assuming homogeneous information needs across space)

DARPATECH 2000 ISO

Grid Transition Plan

- **Beta Release of Grid (FY99- 3QFY00)**
  - CoABS demo described previously
  - Working with other DARPA Programs (ALP, CPoF, AIA)
- **Military Transitions Focus of 3QFY00-FY02**
  - Navy Fleet Battle Experiments (Funded by CoABS)
  - Air Mobility Command (Funded by AFRL, uses Grid)
  - Bilateral Air Planning (Funded by UK DERA, AFRL; uses Grid)
  - Intelink Management Office (Funded by IMO, DARPA)
  - Possibility of use for CC21 ACTD (ONR lead)

DARPATECH 2000 ISO

New Program: DAML (DARPA Agent Markup Language)


```
<Title> Beyond XML
    <subtitle> agent semantics </subtitle>    </title>
<USE-ONTOLOGY ID="PPT-ontology" VERSION="1.0" PREFIX="PP" URL=
"http://iwp.darpa.mil/ppt.html">
<CATEGORY NAME="pp.presentation" FOR="http://iwp.darpa.mil/jhendler/agents.html">
<RELATION-VALUE POS1 = "Agents" POS2 = "/jhendler">
```


DAML:

Create technologies to enable software agents to identify, communicate with, and understand other software agents dynamically (i.e., on the fly at run time, not built in at development time).


```
<ONTOLOGY ID="powerpoint-ontology" VERSION="1.0" DESCRIPTION="formal model for
powerpoint presentations">

<DEF-CATEGORY NAME="Title" ISA="Pres-Feature" >
<DEF-CATEGORY NAME="Subtitle" ISA="Pres-Feature" >

<DEF-RELATION NAME="title-of"
        SHORT="was written by" >
    <DEF-ARG POS=1 TYPE="presentation">
    <DEF-ARG POS=2 TYPE="presenter" >
```

DARPATECH 2000 ISO

DARPA Agent Markup Language

- **DARPA is working on the development of the DARPA Agent Markup Language (DAML)**
  - A "semantic" language that ties the information on a page to machine readable semantics (ontology)
    - Currently being explored at University level
      - SHOE (Maryland), Ontobroker (Karlsruhe),OWL (Washington Univ)
      - Largely grows from past DARPA programs (I3, ARPI)
    - But not transitioning
      - W3C focused on short-term gain: HTML/XML

```
<Title> Beyond XML
     <subtitle> agent semantics </subtitle>     </title>
<USE-ONTOLOGY ID="PPT-ontology" VERSION="1.0"
PREFIX="PP" URL= "http://iwp.darpa.mil/ppt..html">
<CATEGORY NAME="pp.presentation"
FOR="http://iwp.darpa.mil/jhendler/agents.html">
<RELATION-VALUE POS1 = "Agents" POS2 = "/jhendler">
```

```
<ONTOLOGY ID="powerpoint-ontology" VERSION="1.0"
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       <DEF-ARG POS=1 TYPE="presentation">
       <DEF-ARG POS=2 TYPE="presenter" >
```
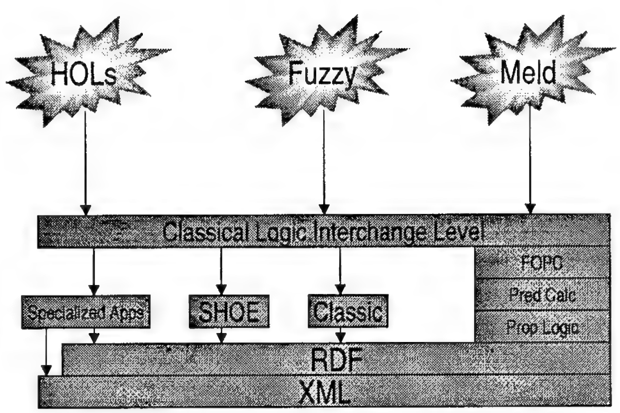


DARPATECH 2000 ISO

DoD and W3C working together



DAML and the "Semantic Web"

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TASK
Description

Create the engineering discipline of agent-based computing

Infinite-horizon problems: $V_t = V_{t'}$ for any t and t'.

1. Expected value per time step
2. Expected cumulative value until goal reached (*e.g.*, $E(\tau)$)
3. Expected discounted cumulative value for discount $0 \le \gamma \le 1$

Discounted case

- The value of being in state x after n stages is $\gamma^n V(X = x)$.
- Let $\Omega_X = \{1, 2, \ldots\}$ and the state transition probabilities

$$p_{ij}(d) = \Pr(X_t = j \mid X_{t-1} = i, D_t = d) \qquad i, j \in \Omega_X \qquad d \in \Omega_D$$

- A policy δ maps states Ω_X to actions Ω_D
- Expected discounted cumulative value for policy δ and state i

$$E_\delta(\Sigma_\gamma \mid X = i) = V(X = i) + \gamma \sum_{j \in \Omega_X} p_{ij}(\delta(X = i))\, E_\delta(\Sigma_\gamma \mid X = j) \qquad i \in \Omega_X$$

- The *optimal expected discounted cumulative value*

$$E(\Sigma_\gamma \mid X = i) = \max_\delta E_\delta(\Sigma_\gamma \mid X = i) \qquad i \in \Omega_X$$

- Which satisfies the *optimality equation*

$$E(\Sigma_\gamma \mid X = i) = \max_d \left[V(X = i) + \gamma \sum_{j \in \Omega_X} p_{ij}(d)\, E_\delta(\Sigma_\gamma \mid X = j) \right] \qquad i \in \Omega_X$$

Optimal Bayesian State Estimator

$$\pi(t)(x) = \frac{\Pr(y(t) \mid X_t = x) \sum_{x' \in \Omega_X} \Pr(X_t = x \mid X_{t-1} = x', u(t))\, \pi(t-1)(x')}{\sum_{x'' \in \Omega_X} \left[\Pr(y(t) \mid X_t = x'') \sum_{x' \in \Omega_X} \Pr(X_t = x'' \mid X_{t-1} = x', u(t))\, \pi(t-1)(x') \right]}$$

15

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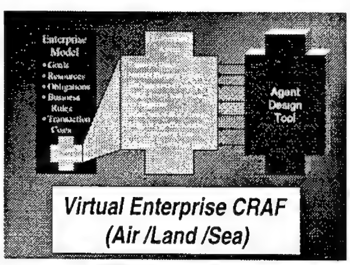
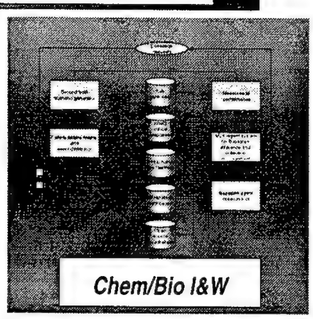
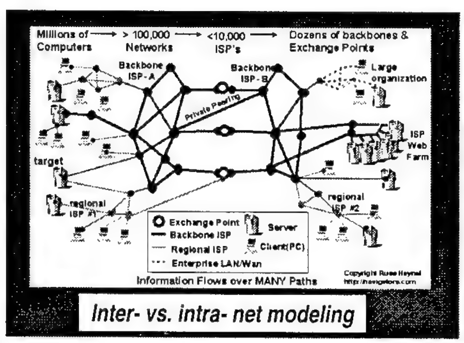
TASK
Challeng(ing) Problems



Virtual Enterprise CRAF (Air /Land /Sea)



Chem/Bio I&W



Inter- vs. intra- net modeling

Task PIs will "strut their stuff" against three currently unsolvable problems

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DARPATECH 2000 ISO

Conclusions

- **Agents are important to the military...**
  - Across a wide variety of problems
    - Early results already exciting
- **... But much R&D remains to be done**
  - Just because it is software, it does not have to be soft science...
    - Solid experimental studies can be performed
  - ... But the theory of computing needs fixing
    - Largely based on a 40-year old model of computation
- **DARPA is taking the DoD lead in understanding this new form of computation**
  - CoABS: Ongoing program (3rd year)
  - DAML/TASK: New Starts, BAA still open (16 DAML projects & 15 TASK projects already funded)

DARPATECH 2000 ISO

"Press clippings"

From DSB "21st Century Defense Technology Strategies", Nov. 1999
"A key program at DARPA in this technology area is called CoABS. The goal of this program is to design, implement, and test a prototype 'agent grid'...[the DoD] must continue to fund the science and technology initiatives that will lead to the intellgent agents envisioned herein. DARPA and the Service laboratories have focused their resources on developoing intelligent agent technology that leverages and supplements private-sector technologies in order to meet warfighter needs."

Figure 5-4 shows one approach to building such a grid of agents, currently under development in DARPA's Control of Agent-Based Systems (CoABS) initiative ... This combination of agent-based codes, agent mark-up languages, and an interoperability infrastructure that enhances agent (and legacy) communication provides an "information web" structure that goes beyond the specific needs of the JBI. However, the study team sees this infrastructure as a military necessity, and the study team joins the Defense Science Board and others in endorsing the military development of such an approach ... transition of DARPA agent technology to AFRL has begun, and the study team recommend high priority be given funds for this transition -- **From AF SAB, "Building the Joint Battlespace Infosphere", Nov. 1999**

"An effort is about to begin to establish a new agent language intended to progress well beyond current Web languages (HTML, XML) that will provide readable (interoperable) semantics." **From NSB, "Network-Centric Naval Forces", 2000**

"DAML could take search to a new level", PC Week, Feb. 7, 2000

"A new language known as DAML addresses an important unmet need — making Web sites more understandable to programs and nontraditional browsing devices...One advantage DAML may have over other emerging web technologies is the involvement of DARPA, which has been instrumental in the creation of the Internet and many internet technologies."

Fleet Battle Experiment (FBE) reviews by CDR, USN
"I believe we have made significant strides in application of the agent technology to the Navy future warfighting concepts. I view CAST as a long term investment--the acorn that may grow into a giant oak tree 5-10 FBEs down the road. FBEs are conducted every six months and are iterative, incremental concept development events and we are very supportive of continued CAST involvement in future FBEs."

DARPATech 2000

Advanced Technology Office Overview

Dr. Thomas Meyer
ATO Director
September 2000

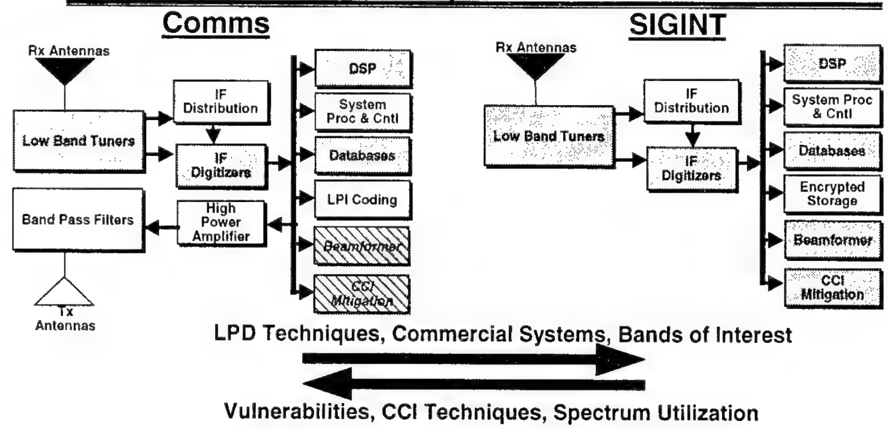
Focus Areas

- Communications
- Maritime
- Early Entry/Special Operations

DARPA

Convergence of Comms, SIGINT, and EW

ATO

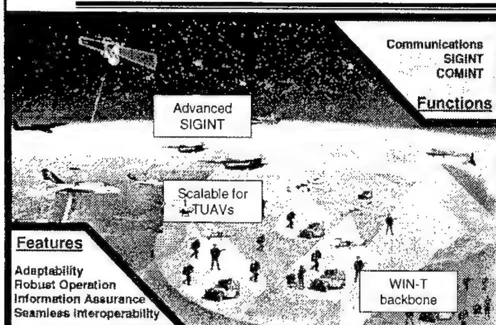


- Opportunity for multi-mission platforms
- Synergistic capabilities
  - Ex: SIGINT can find "holes" in spectrum for transmission
- Platforms can work together for "direction finding", conduct IW, ...

DARPA

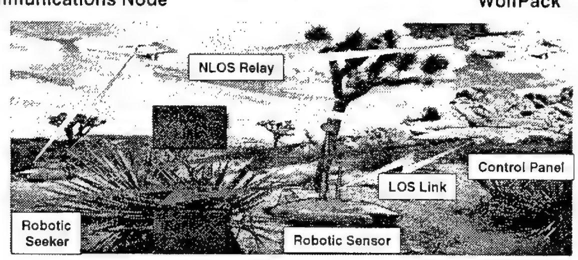
Communications Programs

ATO



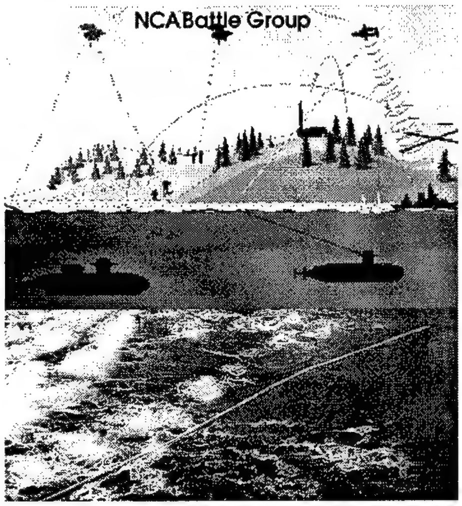
Airborne Communications Node

WolfPack



Future Combat Systems

Buoyant Cable Antenna Array (BCAA)

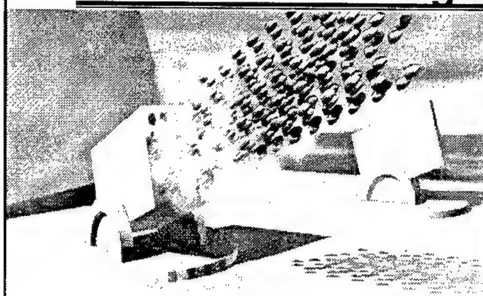


- Joint DARPA/Navy prototype effort
- Coherently combine signals from multiple, floating, inter-connected antenna elements to provide high data-rate submarine connectivity
- Satellite-limited connectivity to a submarine at depth and speed

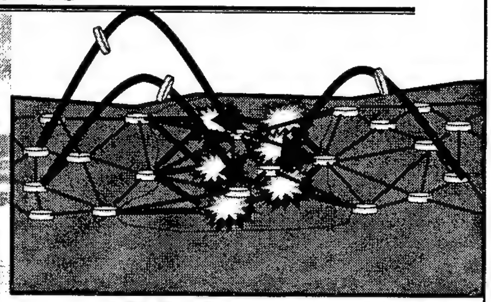
Communications Challenges

- **Bandwidth**
- **LPD/LPI Waveforms**
- **RF Information Assurance**
- **Mobile Ad-hoc Networks**
- **Accurate Geolocation**

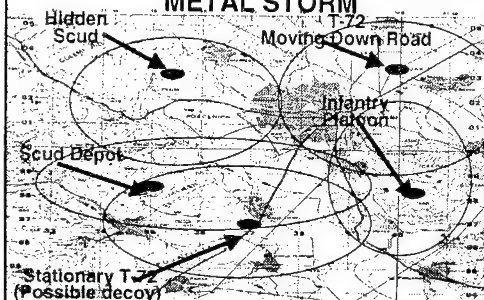
Early Entry/Special Operations Programs



METAL STORM



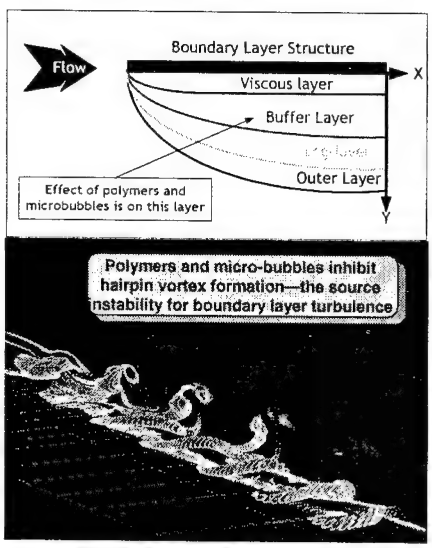
SELF-HEALING MINEFIELD



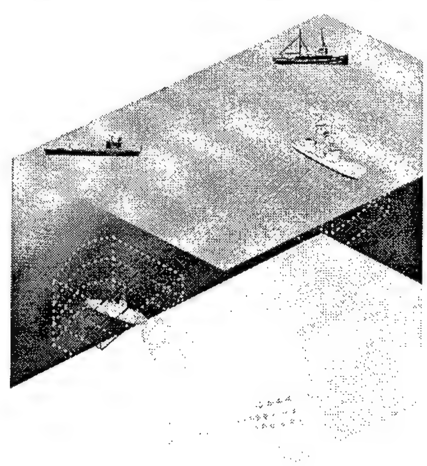
TACTICAL SENSORS

TACTICAL MOBILE ROBOTICS

Maritime Programs



Friction Drag Reduction



Robust Passive Sonar

DARPA ATO

ATO Staff

- **Dr. Thomas Meyer**, Director
  - **Dr. William Jeffrey**, Deputy Director
    - Business Office
      - Mr. Patrick Bailey
      - Ms. Cynthia McCain
    - Communications
      - Dr. Paul Kolodzy
      - Mr. George Duchak
      - Dr. James Freebersyser
      - Dr. Kwan Kwok
      - Dr. Frank Patten
      - Mr. Rob Ruth
    - Early Entry / Special Operations
      - Dr. Art Morrish
      - Dr. Parney Albright
      - Dr. Tom Altshuler
      - LTC John Blitch, USA
      - Dr. Ed Carapezza
      - Mr. Michael Mattice
    - Maritime
      - CAPT John Kamp, USN
      - Dr. Tom Green
      - Dr. Theo Kooij

http://www.darpa.mil/ato

DARPA ATO

Opportunities

- **New Programmatic Opportunities**
  - **WolfPack**
  - **Future Combat Systems C3**
  - **Robust Passive Sonar**
  - **Friction Drag Reduction**
- **Advanced Technologies BAA for FY01**
  - **Looking for Great Ideas**
- **Looking for great people in all areas**

DARPATech 2000

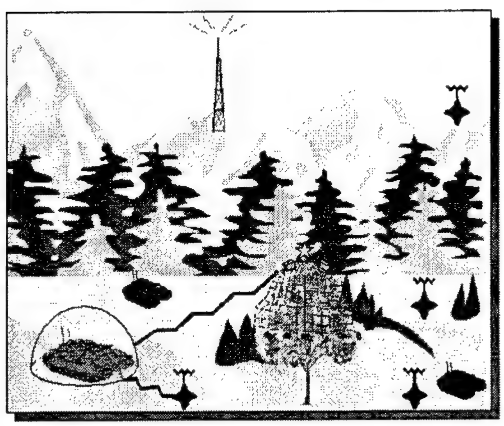
WolfPack

Dr. Paul Kolodzy
Program Manager
(pkolodzy@darpa.mil)

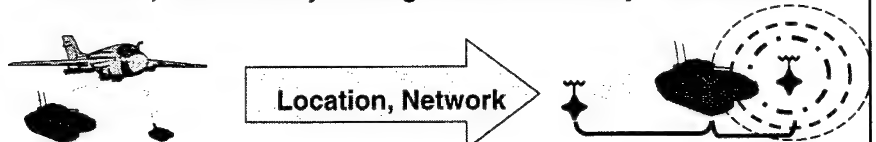
DARPA ATO

WolfPack

- *Deny the enemy the use of radio communications (20 to 2,500MHz) throughout the battlespace by a distributed network of emplaced autonomous, cooperative jammers and*
- *Avoid disruption of friendly/neutral radio communications*



Precision, distributed jamming over a 100 km by 100 km area

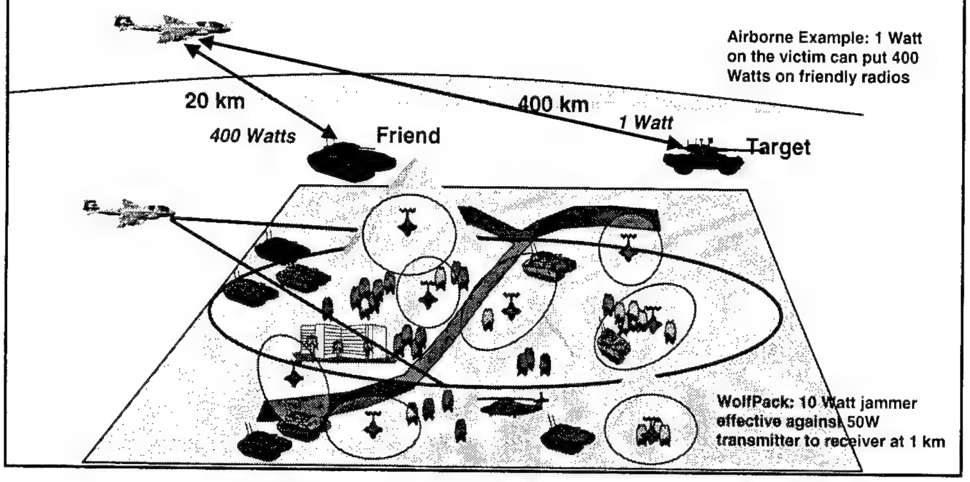


Power, Directivity

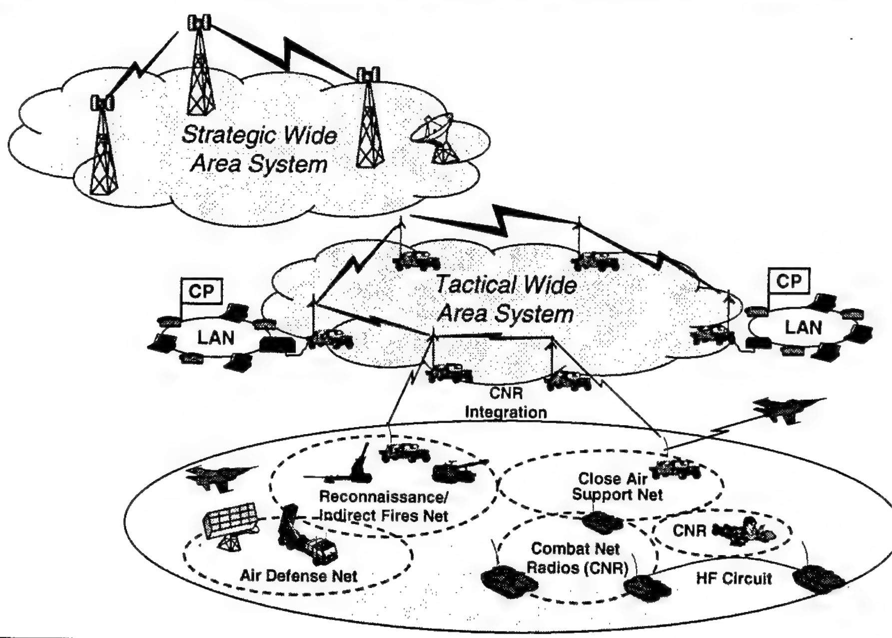
Range, Selectivity

Distributed Jamming

- Airborne jammers can impact friendly communications (Near-Far Problem)
- WolfPack networked, close-approach jamming concept
  - Precisely reacts to target emitters with low power and energy requirements
  - Significantly reduces Blue communications fratricide



WolfPack Target Signals



DARPA ATO

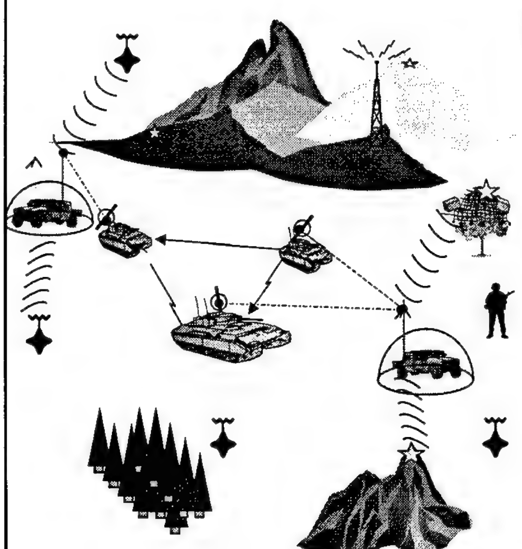
Prevent Enemy Reporting and Coordination of Ground Forces

Electronic Counter Measures Mission

- Spectrum Characterization
  - ➢System detects transmissions
  - ➢Determines network links and nodes, and projects intent
- WolfPack Reaction
  - ➢Prevent (jam) link closure
  - ➢Exfiltrate enemy emitter information
- Result
  - ➢Enemy C2 denied and targets identified

DARPA ATO

Prevent Enemy Detection of Friendly Communication



Electronic Counter Counter Measures Mission

- Spectrum Characterization
  - ➢ System detects enemy locations and networks
  - ➢ Analyzes friendly networks
- WolfPack Reaction
  - ➢ Raise "local noise level" on friendly force frequency
- Result
  - ➢ Friendly transmissions and intentions are masked

DARPA

Disrupt Enemy Integrated Air Defense System

ATO

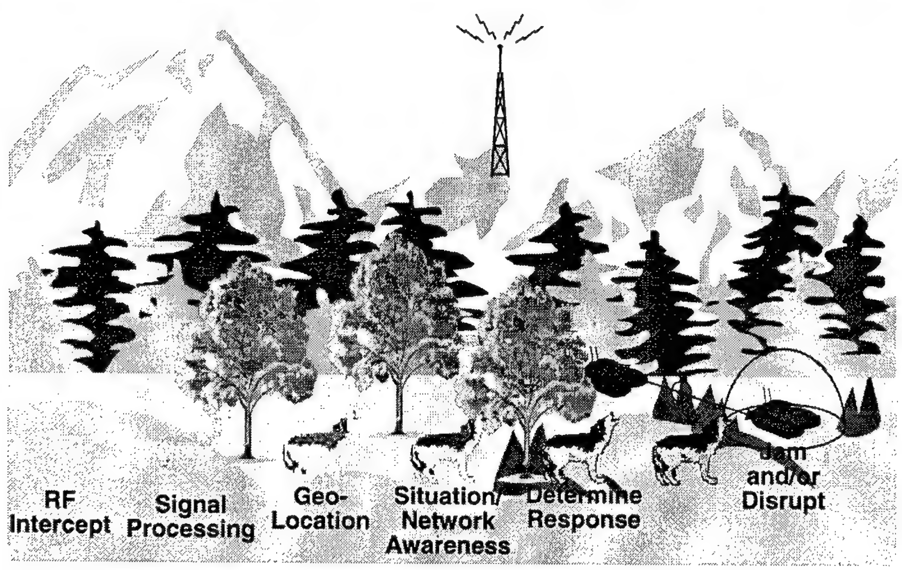
Suppression of Enemy Air Defense Mission

- Spectrum Characterization
  - ➢System deployment characterizes air defense RF environment
- WolfPack Reaction
  - ➢Deny communication link
  - ➢Jam radar receiver
  - ➢Geolocate/Target RF nodes
- Result
  - ➢Defeats side lobe canceling, PRI-agile radars

DARPA

“WolfPack” Technologies

ATO



DARPATech 2000

Warfighter Visualization

Dr. Norman Whitaker
nwhitaker@darpa.mil

DARPA

Thrust Areas

ATO

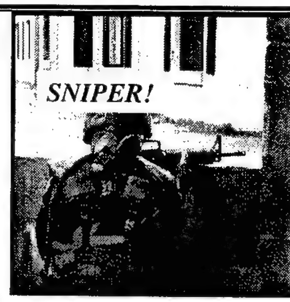
- Visualization Tools for Individuals and Small Teams
- 2D and 3D Environments
- Targeting from Unmanned Aerial Vehicles

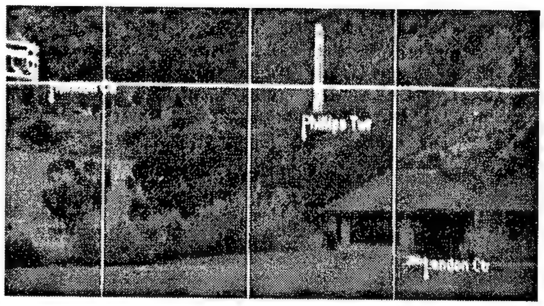
DARPA

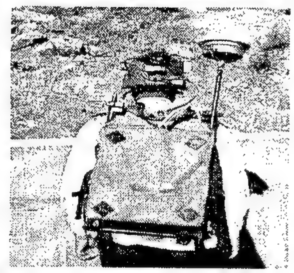
Warfighter Scene Overlays

ATO

•Tactical annotations in "warfighter coordinates"





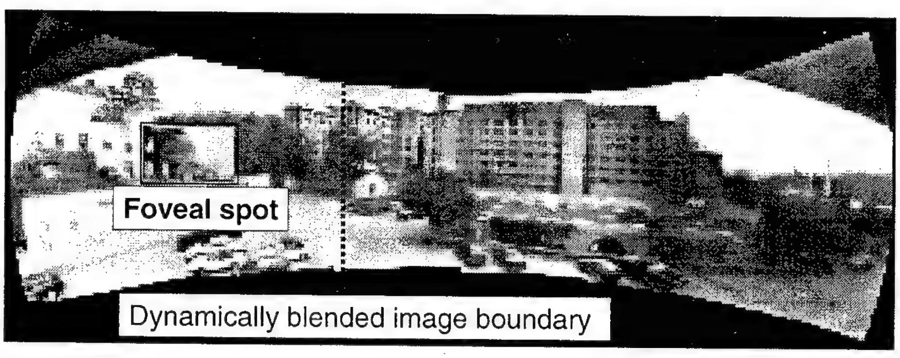


USC, HRL

DARPA

See Through Turret

ATO



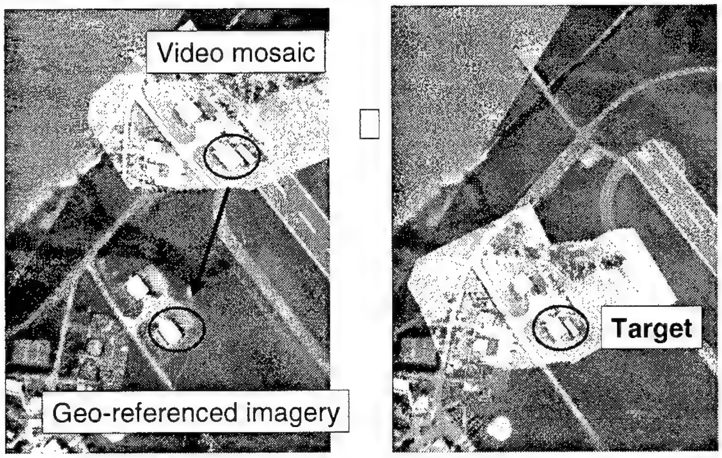
• 360° views for "buttoned up" commander

Honeywell, Sarnoff

DARPA

Real-time UAV Video Geo-registration

ATO



TIGER Targeting System: Used during Allied Force

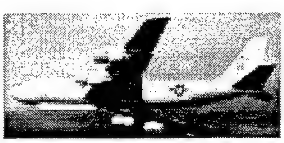
Sarnoff, Cambridge Research

DARPA

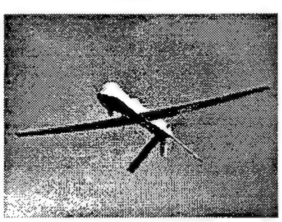
JSTARS-UAV Cross-Cueing

ATO

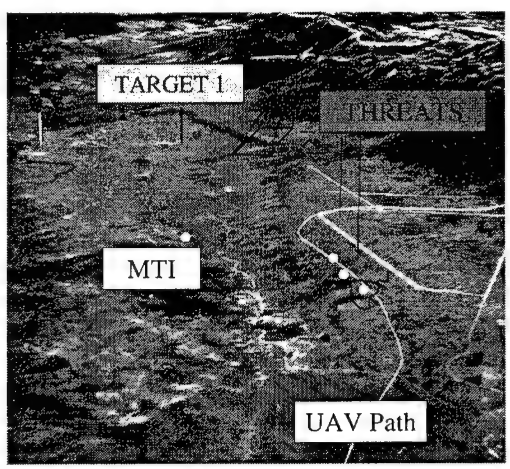
- **Visualization for UAV sensor operator**



JSTARS



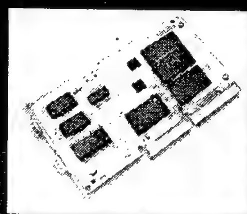
PREDATOR

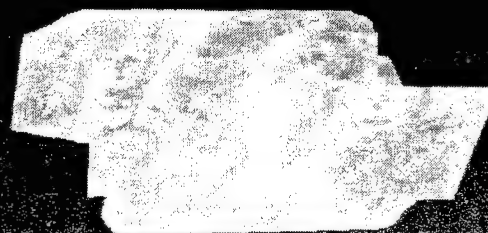


Cambridge Research, USAF UAV Battlelab

Sample Acadia Chip Capabilities

DARPA ATO





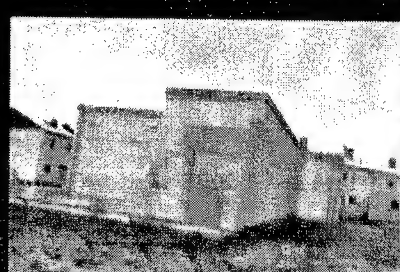
Moving Target Indication

3D Visualization

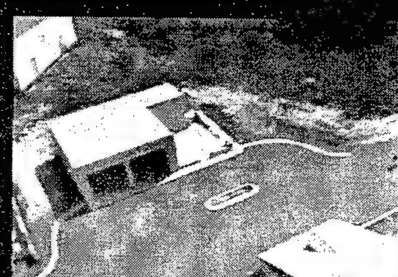
DARPA ATO

GOALS

- Registration of video to 3D model
- Projection of new views



Raw ground video



Raw aerial video

Sarnoff

DARPA

3D Visualization Results

ATO

Video registered to model

"Flashlight" video

Re-rendered view

Runner's Viewpoint

DARPA ATO

Airborne Communications Node (ACN)

George Duchak

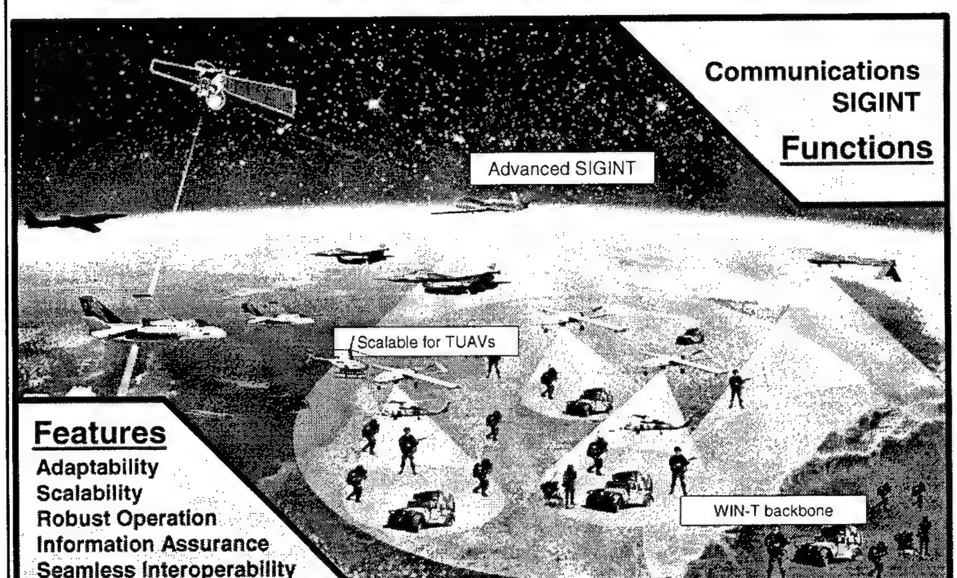
(gduchak@darpa.mil)

DARPA

ACN390v001

DARPA ATO

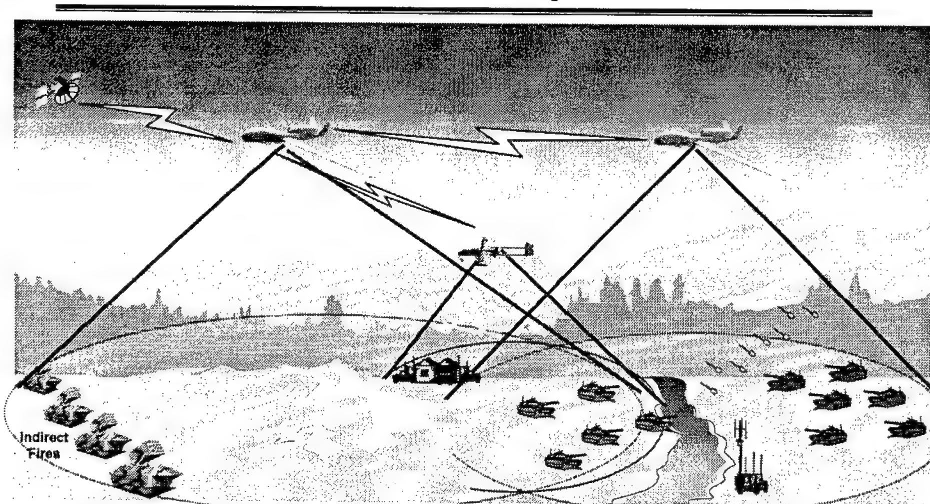
Airborne Communications Node (ACN) Concept



DARPA

ACN Utility

ATO



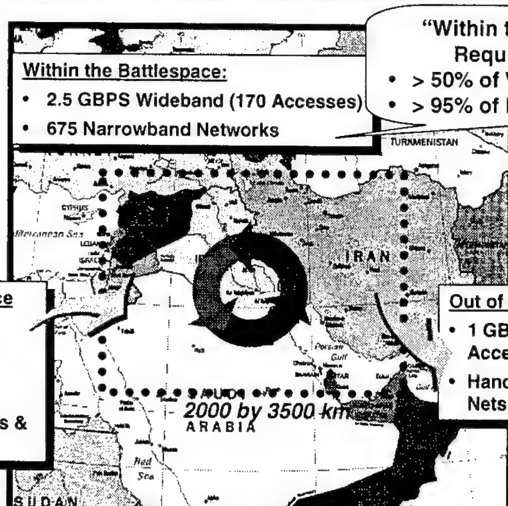
- BLOS Connectivity
- Relief of SATCOM Oversubscription
- "Surge" Communications and Tactical SIGINT Capacity
- Reduced Logistics for Comm Infrastructure
- Enhanced Mobility
- SIGINT / Communications Synergy

ACN377x001

DARPA

ACN Utility: Relieve SATCOM Oversubscription

ATO



Within the Battlespace:
- 2.5 GBPS Wideband (170 Accesses)
- 675 Narrowband Networks

"Within the Battlespace" Requirements are:
- > 50% of Wideband Total
- > 95% of Narrowband Total

Into the Battlespace
- 1.15 GBPS Wideband (360 Accesses)
- Hand-full of Narrowband Nets & P-Ps

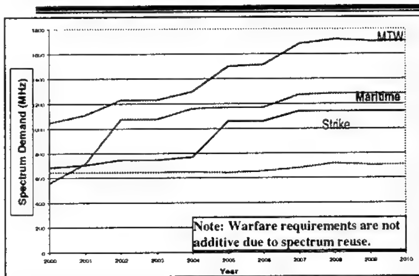
Out of the Battlespace:
- 1 GBPS Wideband (310 Accesses)
- Handful of Narrowband Nets & P-Ps

ACN Can Offload "Within the Battlespace" Accesses and Provide BLOS Connectivity to Fiber Nodes for "Outside the Battlespace" Accesses

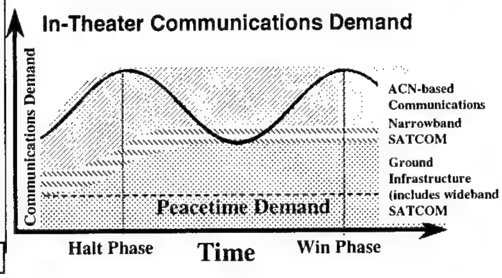
Source: "The Demand for SATCOM Today and in the Future", J6

"Surge" Communications Capacity

DARPA ATO



Theater Fixed-Site Spectrum Demand



Surge Capacity ACN Provides Dynamic "Surge" Capacity to Meet Communications Demands

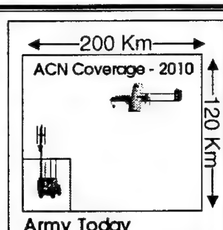
	Global Hawk	CRTUAV	Predator
Frequency	30 MHz - >17 GHz	30 MHz - >2.8 GHz	30 MHz - >17 GHz
BW/Ch	>40 MHz	>40 MHz	>40 MHz
# Channels	>100	> 4	12 - 16
Weight	<900 lbs	20-25 lbs	~100 lbs

Demand from OSAM "Warfighter Spectrum Requirements Analysis", 19 April 2000

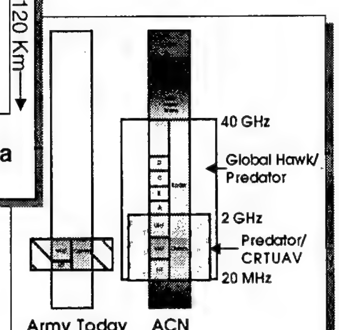
Tactical SIGINT

DARPA ATO

Example Tactical Situational Awareness



Expanded Area Coverage



Expanded Frequency Coverage

Payload Functionality

- Emitter Characterization
- Emitter Geolocation
- Nodal Analysis
- Spectrum Mapping

Reduced Logistics & Improved Mobility

DARPA | ATO

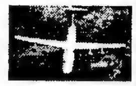
Army Gulf War Communications Infrastructure

ARMY COMMUNICATIONS

- One Theater Signal CMD
- Three Signal Bde HQS
- One JCSE
- Five EAC Signal BNS
- Eight Corps Signal BNS
- Eight DIV Signal BNS
- ~ 13,000 Soldiers

LIFT

- 40 C5s



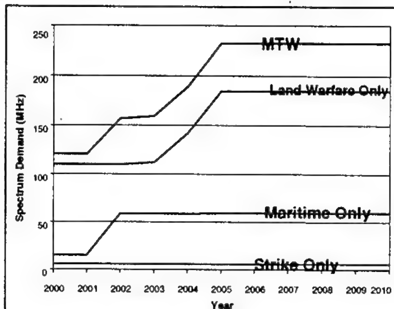
- 24 Ships

Mobility

- ***Demand for Mobile Communications Services Will Increase 92% by 2005***
- ***Supports Mobile Ad Hoc Networking***

Logistics

ACN Reduces the Support Required to Build and Maintain the Comm and SIGINT Infrastructure

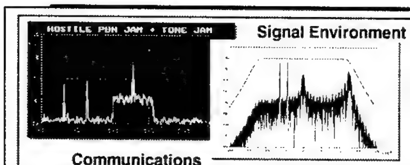


Mobile Spectrum Demand

Demand from OSAM "Warfighter Spectrum Requirements Analysis", 19 April 2000

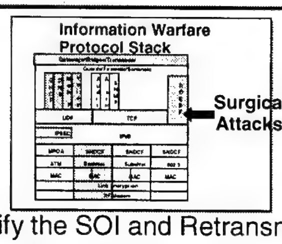
Communications / SIGINT Synergy

DARPA | ATO

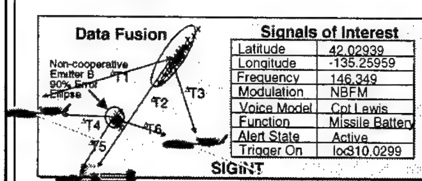


- Wideband Receiver Can Support:
  - + Dynamic Spectrum Allocation -- Transmit in the Spectrum "Holes"
  - + Signals-of-Interest (SOI) Detection

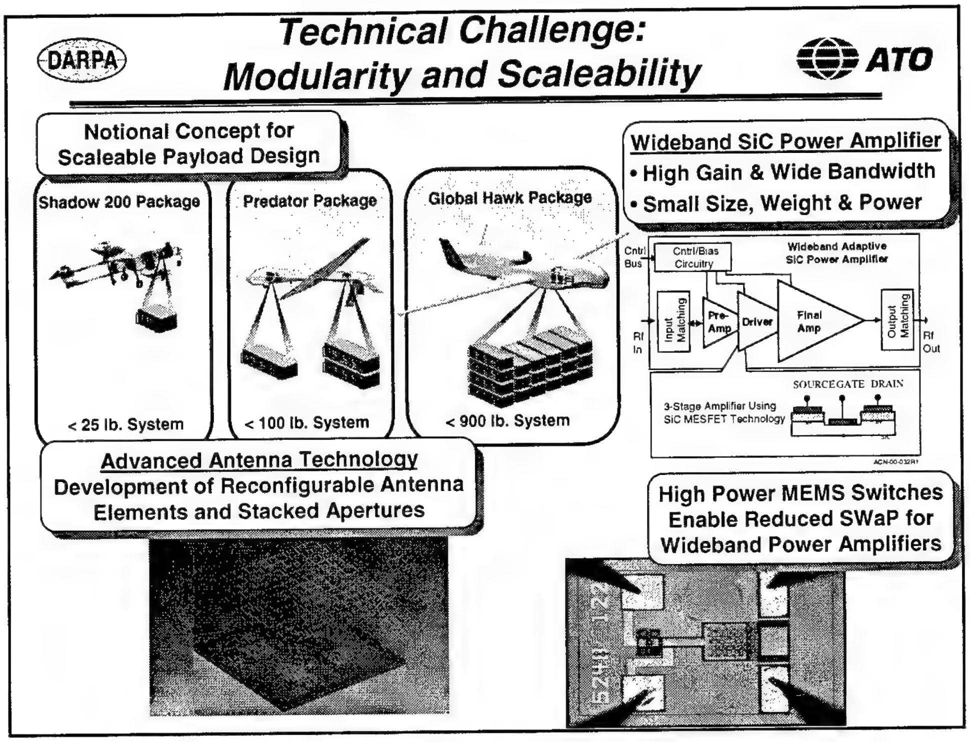
- Onboard Assets Can Track SOI
  - + Crosslinks for Precise Geolocation
  - + Antenna and Signal Processing Supports Tracking with a Single Platform

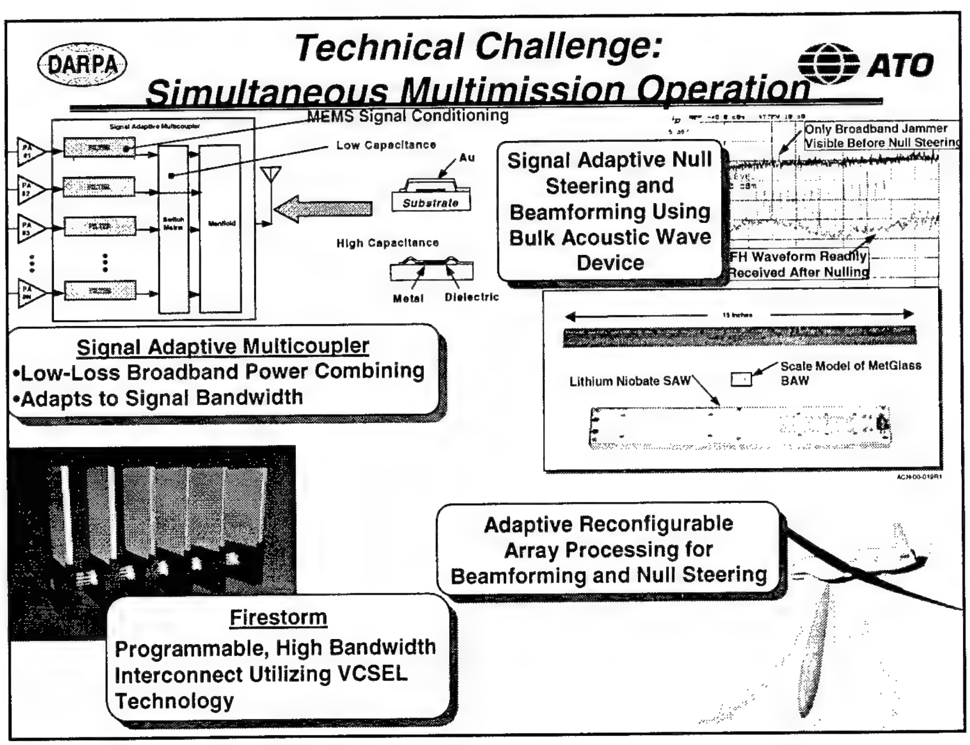


- Modify the SOI and Retransmit the Signal for Information Warfare



- Common Hardware & Software Reduces:
  - + Size, Weight, and Power
  - + Life Cycle Cost


DARPA
Technical Challenge:
Modularity and Scaleability
ATO
Notional Concept for Scaleable Payload Design
Shadow 200 Package
< 25 lb. System
Predator Package
< 100 lb. System
Global Hawk Package
< 900 lb. System
Wideband SiC Power Amplifier
• High Gain & Wide Bandwidth
• Small Size, Weight & Power
Cntrl Bus
Cntrl/Bias Circuitry
Wideband Adaptive SiC Power Amplifier
Rf In
Input Matching
Pre-Amp
Driver
Final Amp
Output Matching
Rf Out
SOURCEGATE DRAIN
3-Stage Amplifier Using SiC MESFET Technology
Advanced Antenna Technology
Development of Reconfigurable Antenna Elements and Stacked Apertures
High Power MEMS Switches Enable Reduced SWaP for Wideband Power Amplifiers


DARPA
Technical Challenge:
Simultaneous Multimission Operation
ATO
MEMS Signal Conditioning
Low Capacitance
Au
Substrate
High Capacitance
Metal
Dielectric
Signal Adaptive Null Steering and Beamforming Using Bulk Acoustic Wave Device
Only Broadband Jammer Visible Before Null Steering
FH Waveform Readily Received After Nulling
Lithium Niobate SAW
Scale Model of MetGlass BAW
Signal Adaptive Multicoupler
•Low-Loss Broadband Power Combining
•Adapts to Signal Bandwidth
Adaptive Reconfigurable Array Processing for Beamforming and Null Steering
Firestorm
Programmable, High Bandwidth Interconnect Utilizing VCSEL Technology

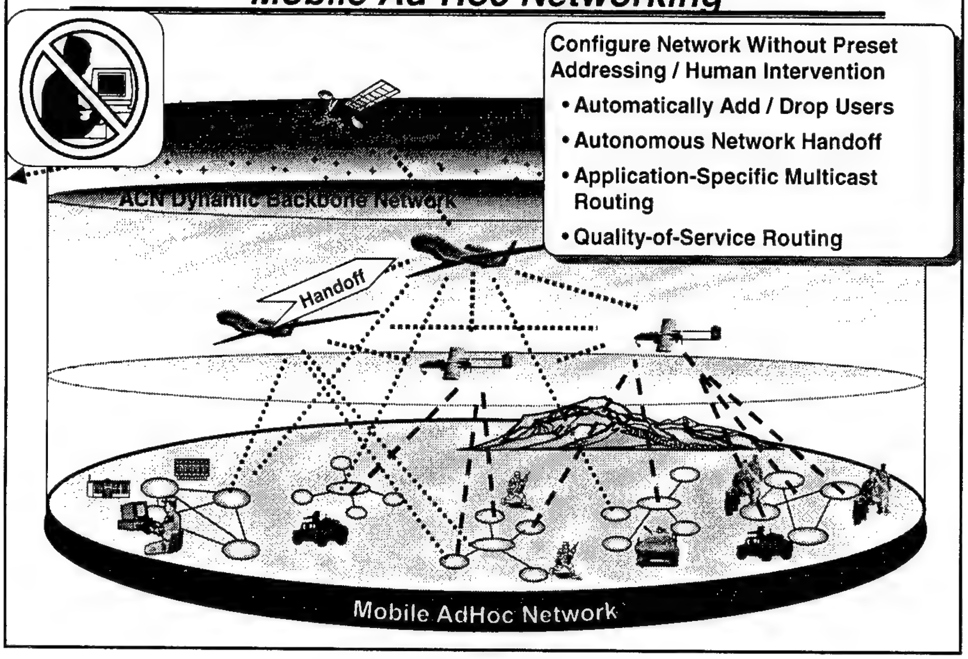
DARPA

Technical Challenge: Mobile Ad-Hoc Networking

ATO

Configure Network Without Preset Addressing / Human Intervention

- Automatically Add / Drop Users
- Autonomous Network Handoff
- Application-Specific Multicast Routing
- Quality-of-Service Routing



DARPA

ACN Opportunities

ATO

Major Program Events	
Phase II Program Kickoff	May 2000
Architecture Review	Sep 2000
System Performance Review	Sep 2001
System Design Review ("PDR")	Jan 2002
Phase III Readiness Review ("CDR")	Aug 2002

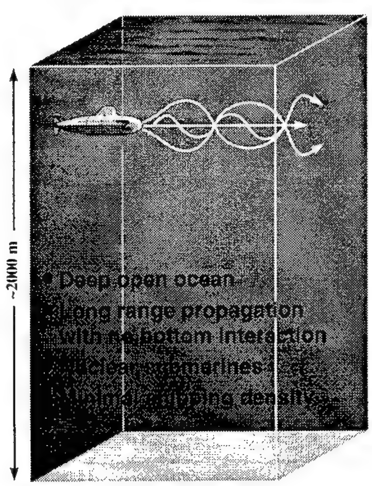
DARPATECH 2000

Robust Passive Sonar

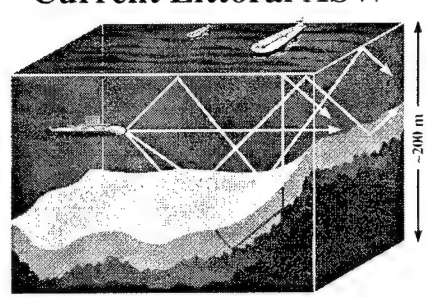
Dr. Thomas J. Green, Jr.
Program Manager
September 2000

DARPA **Anti-Submarine Warfare (ASW)** ATO

Cold War ASW



Current Littoral ASW



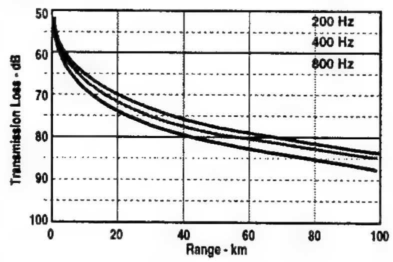
- Shallow water coastal regions
- Multipath propagation with significant attenuation
- Quiet diesel-electric submarines
- Significant shipping noise interference
- Dynamic engagements

Littoral ASW Implications

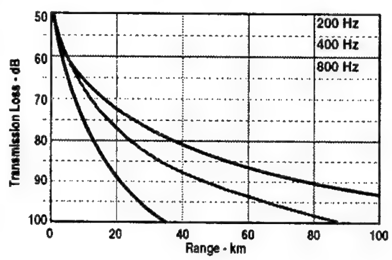
DARPA ATO

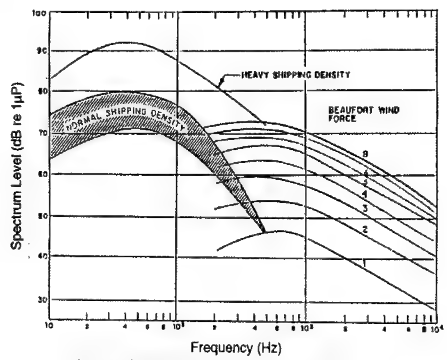
Strait of Korea

April



September



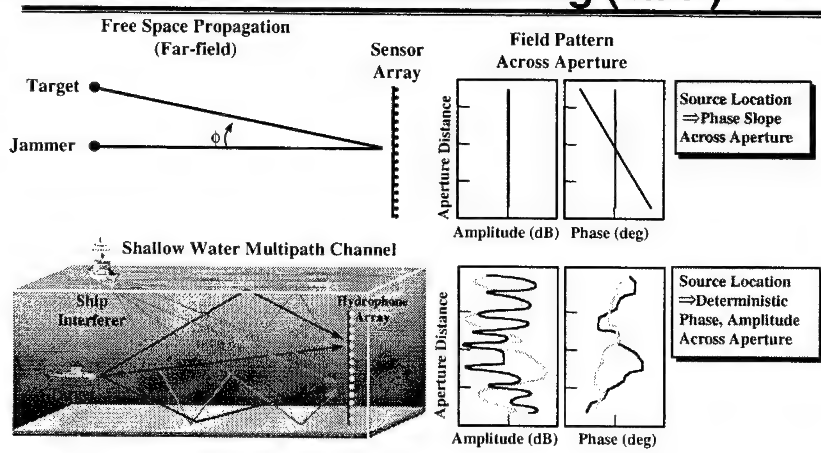


Average Ambient Noise Spectrum Levels (Wenz, 1962)

Loss of sensitivity due to heavy shipping density can produce dramatic reductions in detection range

Matched Field Processing (MFP)

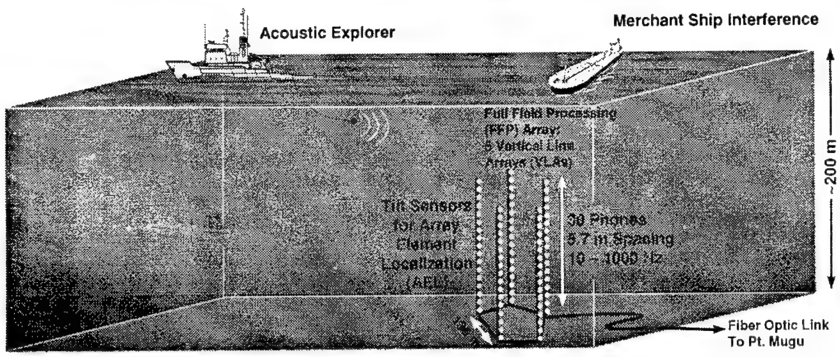
DARPA ATO



- Steering vector derived from propagation model
- Exploits channel multipath for detection/localization
- Adaptivity rejects interference and reduces sidelobes
- Main issues
  - Robustness to environmental uncertainty
  - Estimating scene statistics with limited snapshots

DARPA SB Channel Experiment (SBCX) ATO

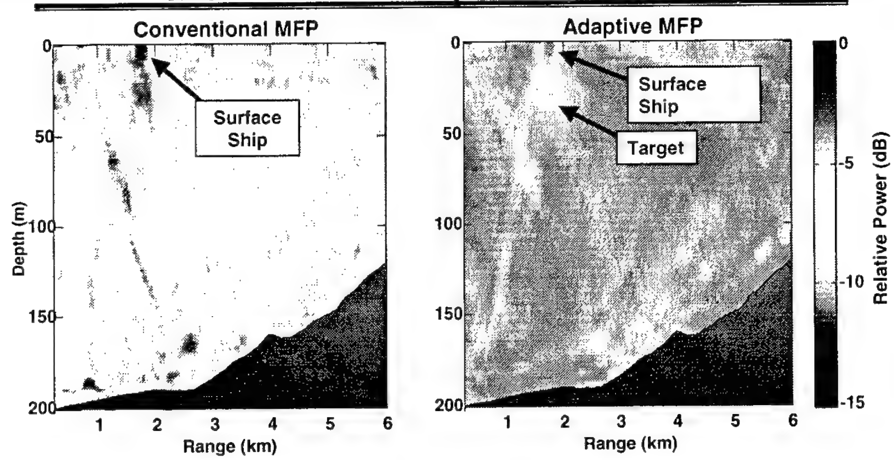
Santa Barbara Channel Experiment (SBCX)



Objectives:

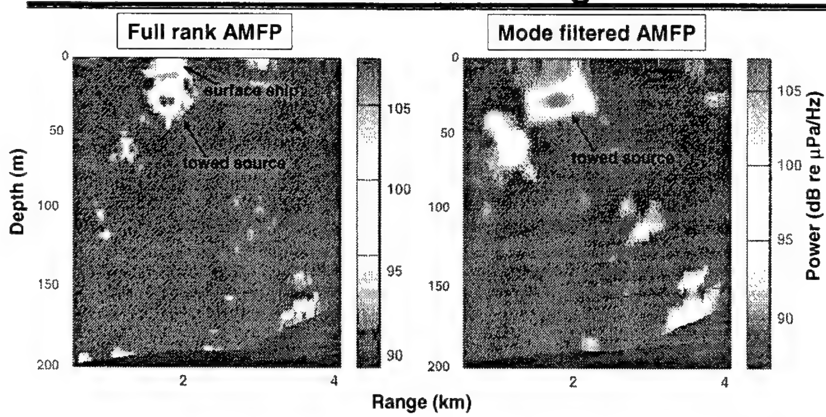
- Establish fundamental limits to signal and noise gains with Adaptive Matched Field Processing (AMFP) for passive broadband detection, localization, and classification
- Extrapolate measured performance to other threats, environments, and sensors of interest

DARPA Adaptive Target Localization with Surface Ship Interference ATO



AMFP utilizes adaptivity and environmental knowledge to provide correct localization of weaker, submerged source in the presence of surface interference

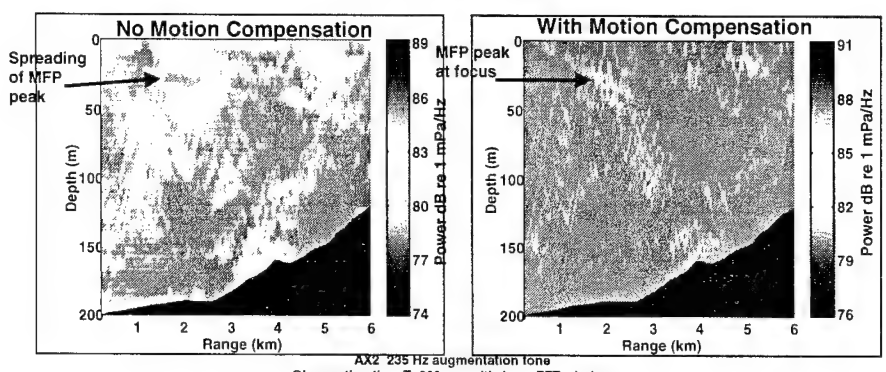
Adaptive MFP with Mode Filtering



- **Modal filtering is designed to remove energy from surface interference while retaining submerged source**
  - **Lessens requirements for adaptive snapshot support**
  - **Broadens MFP beam, decreasing losses from motion and environmental mismatch**

Motion Compensation Processing

Actual range (GPS) 1.70 to 2.45 km



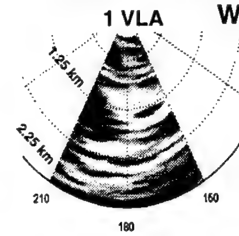
AX2 235 Hz augmentation tone
Observation time T=300 sec with 1 sec FFT window

- **Motion compensation matrix adjusts for phase difference and amplitude ratio of moving target as a function of time**
- **Compensation increases signal gain and mitigates sidelobes**
  - Eliminates smearing loss of 4 dB in the interference-free scenario
  - Additional SINR gain when interferers on different tracks are de-focused

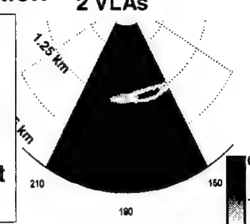
Multi-VLA Processing with Motion Compensation

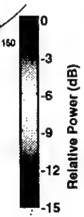
DARPA ATO

Without Motion Compensation

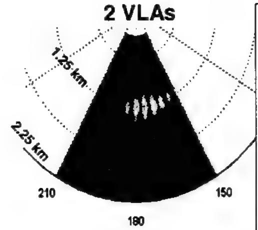


- Tilt of single VLA gives coarse bearing
- Multiple VLA processing gives incoherent average
- Full array resolution not achieved

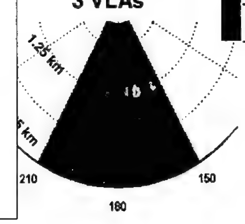




With Motion Compensation



- Differential Doppler across FFP baseline corrected prior to covariance estimation
- Full array resolution achieved with compensation



Data: AX2, 235 Hz

Robust Passive Sonar

DARPA ATO

Target sensors:

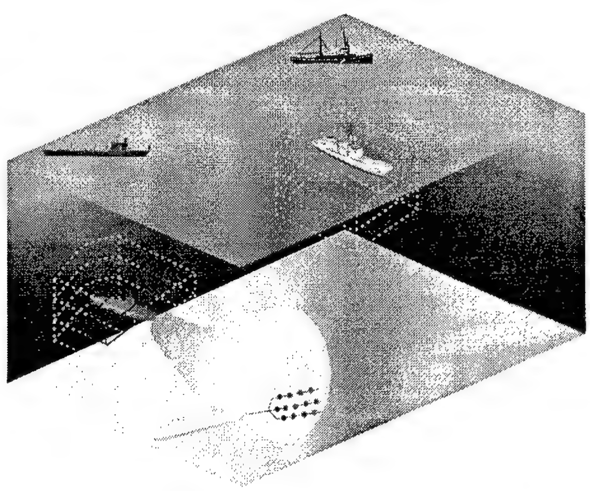
TB-29

- Large aperture with many elements
- Heading sensors to support advanced processing

SURTASS

Twin Line

Prototype Sensors



Revolutionary Tactical Control for Littoral ASW:
> 10 dB Gain in Figure of Merit

DARPA ATO

Approach

- Conduct system analysis for performance assessment
- Extend SBCX concepts to tactical systems
- Integrate processing techniques into end-to-end sonar
- Conduct focused sea tests and experiments
- Utilize high-quality, ground-truthed tactical data sets to verify performance

DARPA ATO

We Need Your Help!

Technology Areas

- Systems analysis
- End-to-End processing systems
- Advanced beamforming concepts
- Automation
- et al.

Procurement Plans

- Broad Agency Announcement
- Unsolicited white papers

New Ideas Needed

DARPA ATO

Drag Reduction Program

Dr. Penrose (Parney) C. Albright
palbright@darpa.mil

DARPA ATO

What are we trying to accomplish?

- Develop friction-drag-reduction technology ...
  - With *demonstrable operational* value to the future naval and/or sealift fleets
  - Using extensive computational modeling and experiments
- We will exploit *new approaches to multi-scale modeling...*
  - Developed within the materials science community
  - Enabled by massively parallel computer architectures

> To develop a *multi-scale modeling capability* for **turbulent flow**

- We will leverage the simulation results to guide *focused* near-full-scale ($Re \sim 10^8$) experiments

Drag reduction implications

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Speed at constant power is a weak function of drag

At least ~50% reduction in friction drag is required to meaningfully *increase speed*

Promising only when residual drag is insignificant

Proportional reduction in fuel consumed at constant speed

Potential increase in payload

- Long-range (long-endurance) ships have large fuel fractions ~0.2-0.5
- Military ships typically have small payload fractions — 0.1 or less
- E.g., 20% friction drag reduction ⇒ ~50% increase in payload

Proportional increase in range and endurance at constant speed

Reductions in friction drag of <~20% probably uninteresting

Where we are today

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Friction drag constitutes...

Roughly 50% of the drag on surface ships

Roughly 65% of the drag on submarines

Decades of research have identified two very promising techniques for reducing friction drag: polymers and microbubbles

70-80% reduction in skin-friction drag coefficient *in the laboratory*

But, success in the *practical* implementation of these techniques has eluded us for more than 25 years

- Too much polymer has to be carried, and the polymer degrades at high speeds
- Power requirements for injecting microbubbles are below the break-even point

Where we are today: Polymers

Key Results

~80% reduction in drag in small-scale lab experiments
- ~50% reduction for short periods in full-scale experiments

Significant recent advances in first-principles modeling
- Direct Numerical Simulation (DNS) with a constitutive relation for the polymer stress tensor
- Excellent qualitative agreement with experimental observations associated with drag reduction
- Indicated potential for optimization
  - E.g., equivalent drag reduction at 1/10 the needed concentration with 3× polymer chain extensibility

Limitations

Number of grid points needed for a DNS simulation of *ship* flow prohibitive

Computational state-of-the-art for polymer modeling $Re_d \sim 5 \times 10^3$

$\sim 10^6$ grid points

Ship $Re_d \sim 10^6$

Number of grid points needed $\sim (Re)^{9/4}$

Where we are today: Microbubbles

Key Results

~80% reduction in drag demonstrated in small-scale experiments

No full-scale data (Japanese planning an experiment)

Limitations

Experimental results at low Re ($\sim 10^6$)

No validated or accepted theory

Rudimentary modeling; No DNS-level computations attempted

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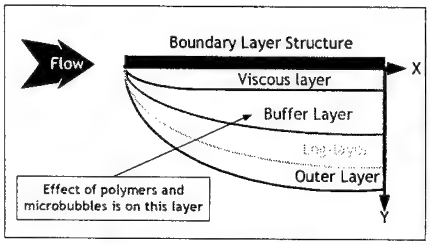
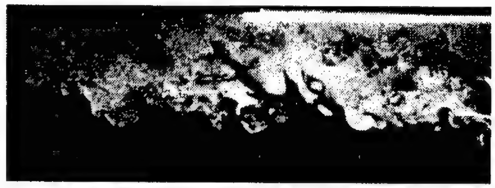
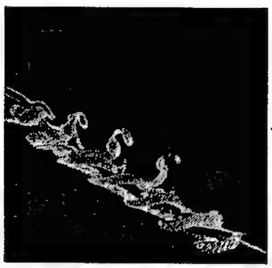
Impact of Polymers and Microbubbles







Polymers and microbubbles inhibit hairpin vortex formation—the source instability for boundary layer turbulence

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Approach (1 of 2)

Develop a *multi-scale* modeling capability

RANS modeling regime
$Re_x \sim 10^8$

LES modeling regime
$Re_x \sim 10^7$

- Models for KE; τ; ε; Π
- Boundary conditions

DNS modeling regime
$Re_x \sim 10^5$

- Exact behavior at all scales
- Detailed modeling of different drag-reduction mechanisms
- Parametric studies

- Subgrid models
- Boundary conditions

Approach (2 of 2)

Perform *focused* experiments

Subscale (e.g., flat plate) experiments to test computational insights

Near-full-scale tests (Re~10^{8+}) with *test-bed models* that address candidate high-payoff friction drag reduction concepts

- With DNS, determine best drag reduction candidates
- With engineering models, determine best implementation candidates

Fully exploiting simulation results at both *small* and *large* scales allows intelligent experimentation that is affordable and effective

Mid-term and Final Exams

Mid-term exam (~2.5 years)

- Have we demonstrated a capability to predict the best techniques for drag reduction and their implementation?
  - If yes, then do we believe we can achieve a 30–50% reduction in skin-friction drag *that can be practically implemented*?
  - If no, then do we have high confidence that a continuation of the computational effort for 2 more years will be successful?

Final exam (4.5 years)

- Have we demonstrated and experimentally validated a predictive modeling capability for skin friction drag reduction?
- Have we demonstrated a 30–50% reduction in skin-friction drag *that can be practically implemented*?
- Are these results validated in near-full-scale experiments?

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Summary

ATO

- Revolutionary friction-drag reduction (~50%) should be established as program goal
- Decades of research can be leveraged to move toward militarily important technology
  - Considerable work done from molecular-scale theoretical through full-scale experimental regimes
  - Not reduced to practice after more than 25 years
- Massively-parallel super computers, computational techniques, and existing experimental facilities could enable a breakthrough
  - Multi-scale modeling of turbulent drag reduction
  - Near-full-scale experiments closely coupled with models

Special Projects Office

James F. Carlini
Director

DARPATech 2000
8 September 2000

Special Projects Office

Dominate Surface Threats
- Moving, Emitting, CC&D
- Underground Facilities
- Entire Kill Chain
  - Surv-Combat ID-Engagement-BDA
- Emphasize Robustness

Counter Emerging Threats
- Chem-Bio Defense Systems
- Cruise Missile Defense

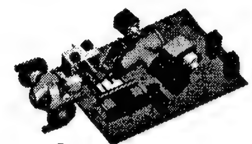
Critical Supporting Technologies/Systems
- Navigation
- Advanced Sensors
- Signal Processing

Chem/Bio Defense Activities

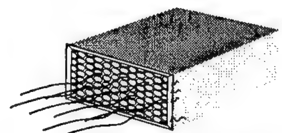
Component Technologies

- Detectors/ID
- Reporters
- Fluidics
- Collector materials
- Decon agents

Component Systems

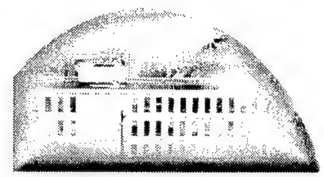


- Sensors



- Filtration, etc.

Complete Defensive Systems



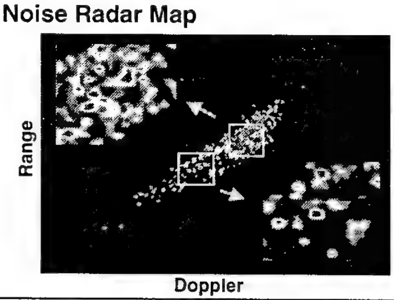
- Building Protection

Low-Cost Missile Defense Technologies

Seekers

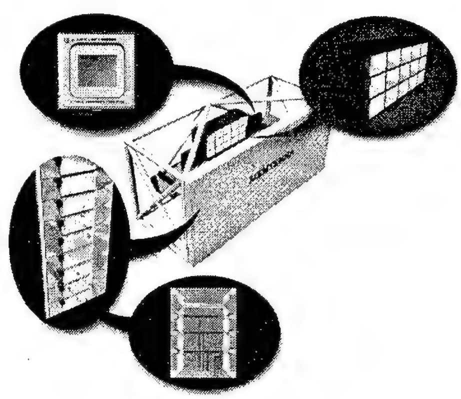
MEMS ESA Antenna

Noise Radar Map



Fire Control Sensors

MEM-tenna



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Surface/Underground Threats

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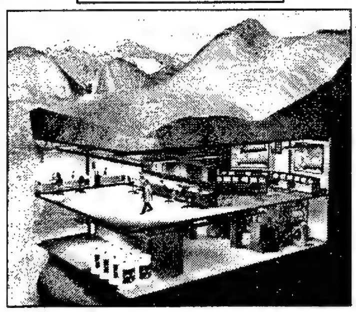
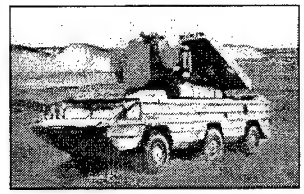
Foliage

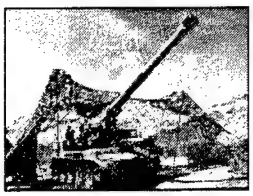
Underground



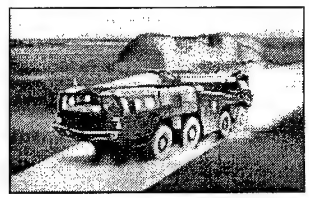
Emitters



Decoys/Deception



Movers



Focus on Entire Kill Chain, Firepower, Affordability

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Counter Underground Facilities

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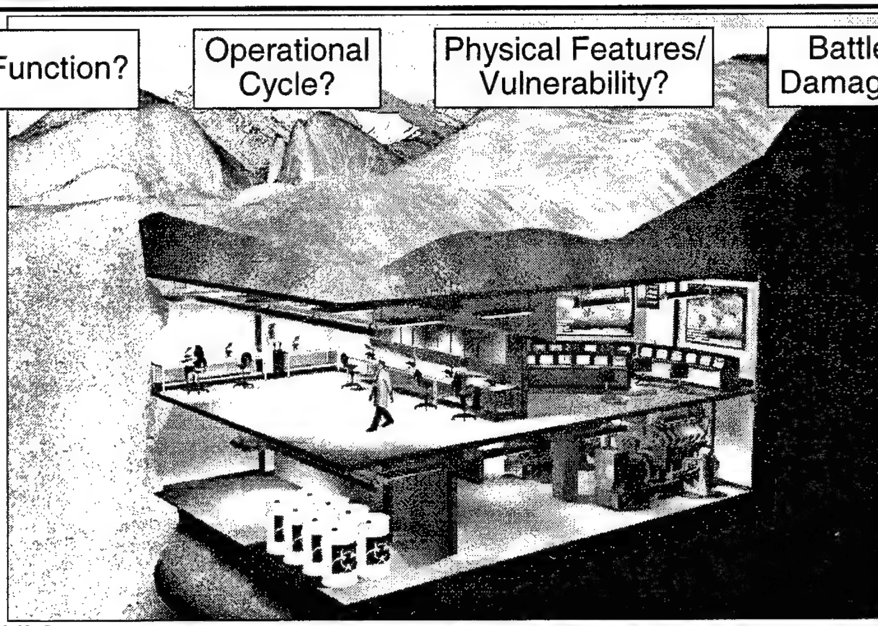
Function?

Operational Cycle?

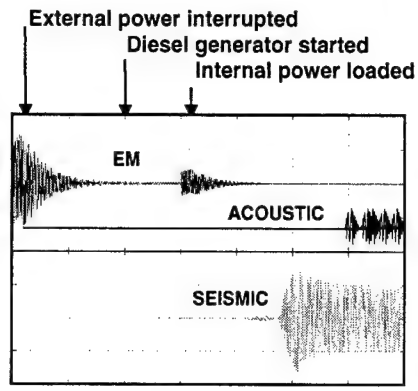
Physical Features/ Vulnerability?

Battle Damage?



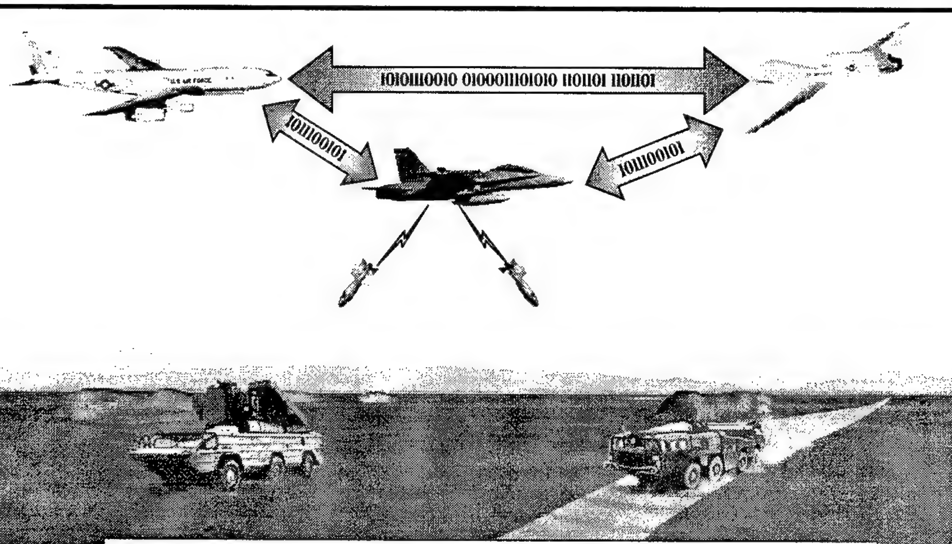
Sample Technical Thrusts

- Passive Acoustic, Seismic & EM (PASEM):
  - Detection and localization of UGF vulnerabilities and operational tempo



- Effluents Detection and Localization:
  - Vents / Facility Function / BDA

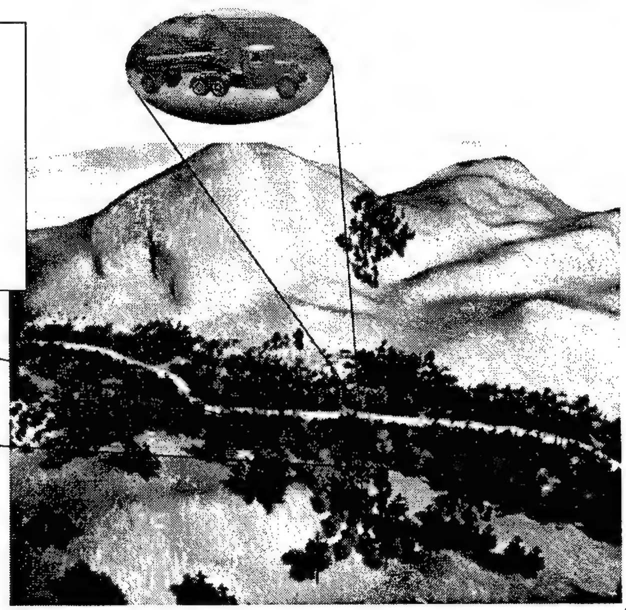
Surface Targets – Movers and Emitters

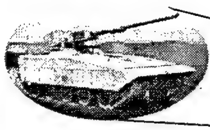


Rapid, Extremely Precise,
Networked Targeting and Engagement

Surface Targets - Foliage

- Challenges:
  - All-terrain GMTI
  - Simultaneous ESM / GMTI / SAR
  - Robust Terrain Characterization
  - Combat Identification

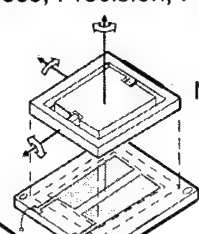




Critical Technologies

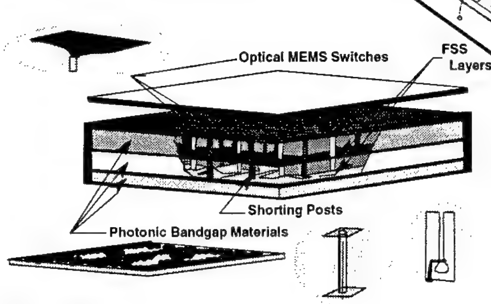
Navigation

Robustness, Precision, Packaging



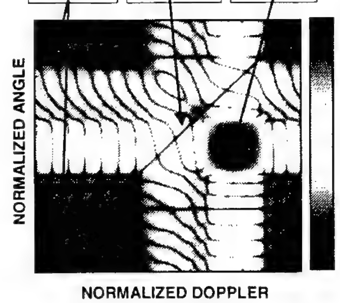
Advanced RF

Radar, ESM, Comm



Signal Processing

Robustness, ECCM



Other Opportunities

- Tactical Networking Technologies
  - Wideband, low latency, reconfigurable
- Real-Time BDA
  - In-mission, all-weather
- Combat ID for Stressing Surface Threats

Points of Contact

• Chem-Bio Defense Systems	Amy Alving, Steve Buchsbaum, Millie Donlon
• Low-Cost Missile Defense Technology	Ed Gjermundsen, John Smith
• Underground Facilities	Dan Cress, Steve Buchsbaum
• Moving Targets (AMSTE)	Steve Welby
• Emitting Targets (AT3)	Jim Carlini
• Concealed Targets, Decoys	Lee Moyer, Bob Hummel

Points of Contact (continued)

• Tactical Targeting Networks	Peter Highnam
• Real-Time BDA	Steve Welby
• Surface Target Combat ID	Bob Hummel, Ed Gjermundsen
• Navigation Technologies	Greg Vansuch
• RF Technologies	John Smith
• Advanced Signal Processing	Joe Guerci

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SPO
Special Projects Office

Biological Warfare Defense Systems

Amy E. Alving
Deputy Director
Special Projects Office

DARPATech 2000
6-8 September 2000

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Chem/Bio Defense Activities

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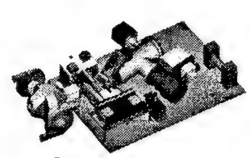
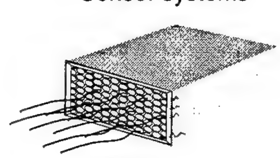
Component Technologies

- Detectors/ID
- Reporters
- Fluidics
- Collector materials
- Decon agents

Component Systems

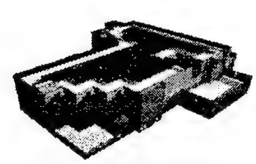


- Sensor systems



- Filtration systems

Complete Defensive Systems



- Building Protection

BWD Timeline

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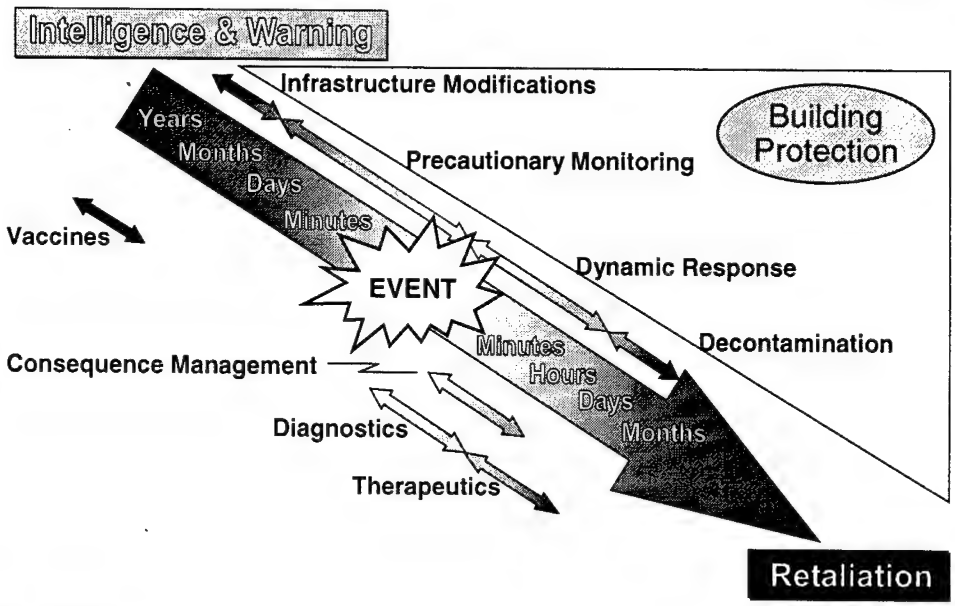


Building Protection

Special Projects Office

Threat:

- Focus is on protecting military buildings (C^2, barracks, ...) from:
  - attack by chem or bio warfare agents;
  - external or internal release.

Goal:

- Make buildings far less attractive targets.

Approach:

- Reduce effectiveness of attack via dynamic response of HVAC (and other) infrastructure.

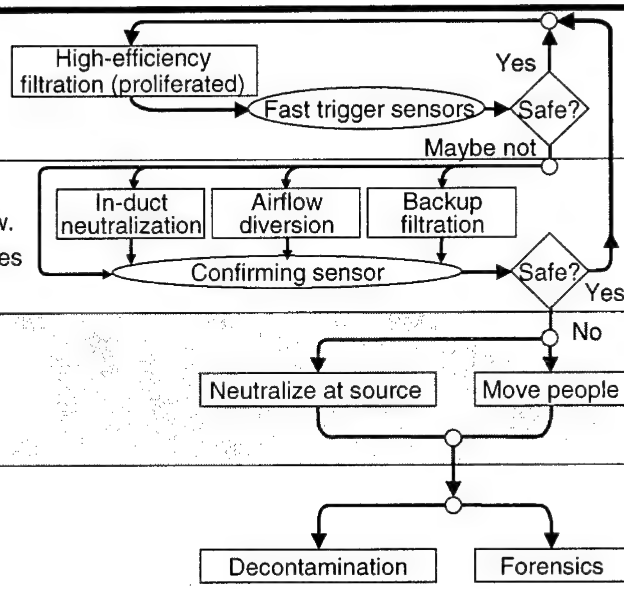
Objectives:

- Protect human inhabitants.
- Restore building to function, quickly.
- Preserve forensic evidence.

DARPA Example Building Protection Architecture

SPO Special Projects Office

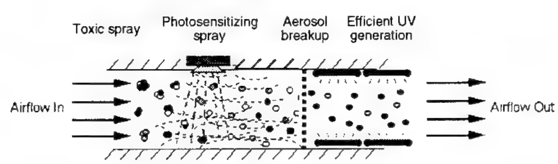
- Normal Operation
  - Clean air continuously.
  - Increased biomass is suspicious.
- Possible Attack
  - Confirming sensors are slow.
  - Take precautionary measures in interim.
- Confirmed Attack
  - Full-scale response.
- Post Event
  - Clean up.
  - Attribution.

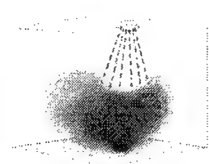


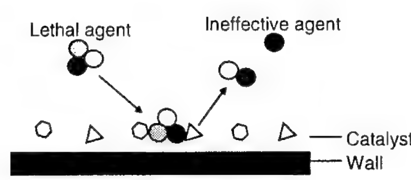
DARPA Technology Development Investments

SPO Special Projects Office

- Neutralization
  - Efficient uv sources
  - Aerosol breakup
  - Photosensitizing agents
  - In-situ, toxic sprays
- Filtration
  - Low-Δp, high-efficiency filters
  - Combined chem/bio filters
  - Neutralizing filters
- Decontamination
  - Self-cleaning surfaces
  - Nano-bombs/emulsions
- Sensors







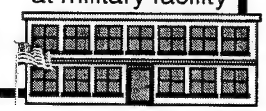
DARPA Integrated System Experimentation & Demo

SPO Special Projects Office

Systems design
- Strategies
- Architectures
- Trades
- Requirements

Systems implementation
- Full-scale testbed of end-to-end system
- Experimentation
- Model validation

Demonstration
- Demo protection at military facility



Systems challenges

- Interpreting sensor response
- Localization of release location
- Optimizing response options
- Robust control algorithms
- Containment of agent at source
- Side effects of neutralization techniques
- Auto calibration/rare-event readiness
- System dependence on threat, release style

- Modeling of component and system behavior and protection afforded

DARPA Building Protection Program Elements

SPO Special Projects Office

FY01 – FY03

Technology Development
- Chem components
- Bio components

Insertion opportunity

FY01 – FY04

Systems Experimentation
- Implement, test, optimize
- Measure system performance:
  - FY01: external release
  - FY03, FY04: internal release

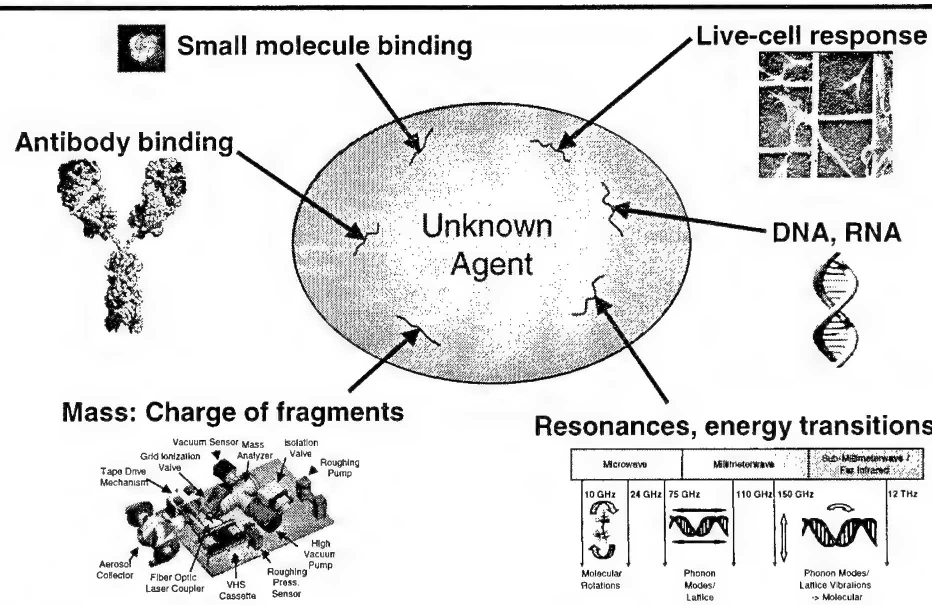
FY04 – FY05

Demonstration
- Military installation
- Based on experiments

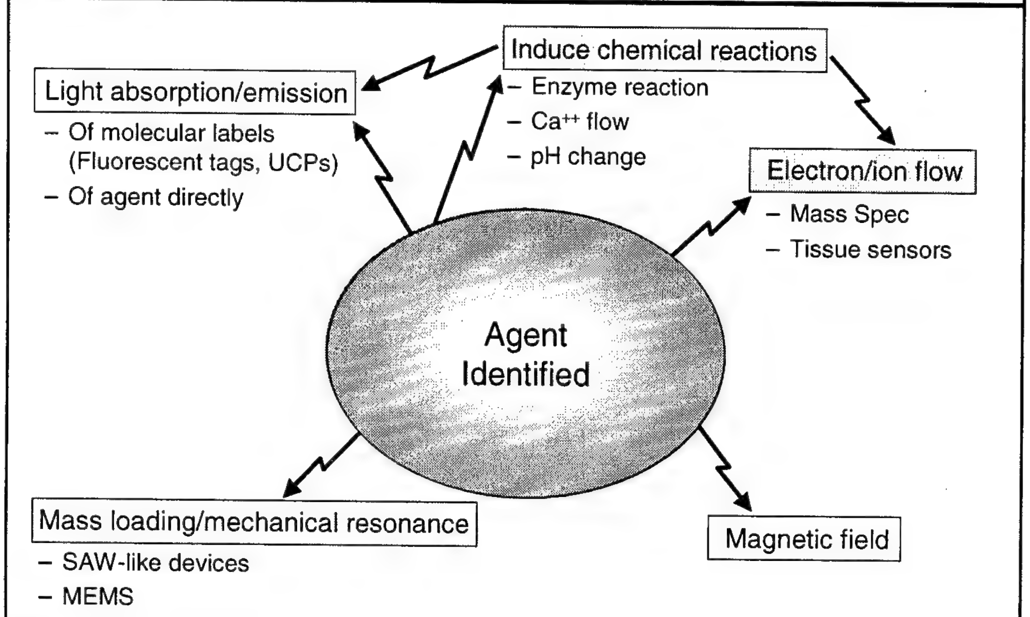
Bio Sensor Needs

- Bio sensors are a key component of many defensive architectures.
- Today's bio sensors do not perform well enough to enable their use in complex architectures.
- Fixing this shortcoming requires both novel sensor technologies and a change in how we design and develop sensor systems.

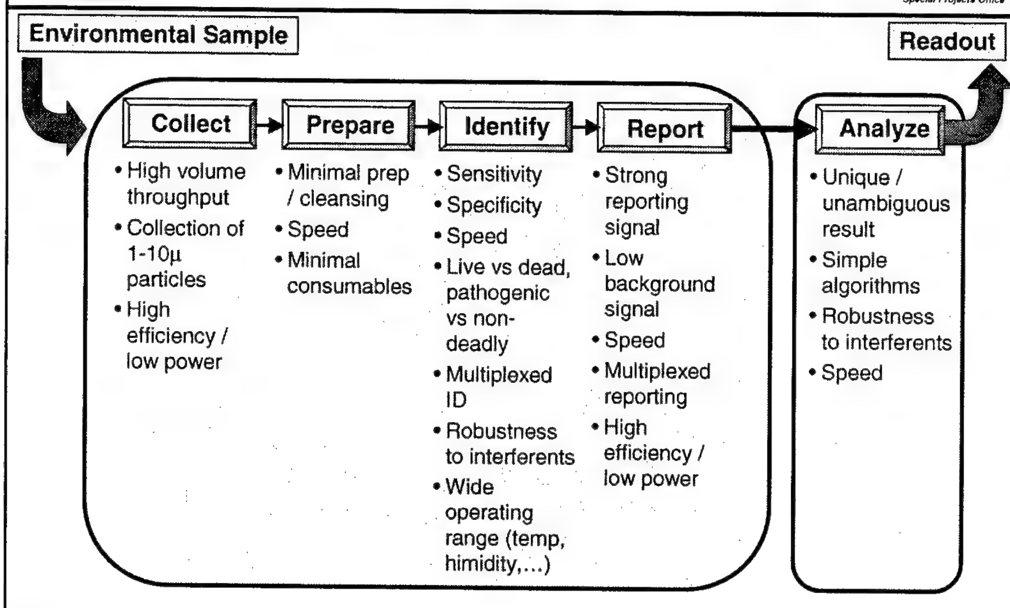
Sensor Systems – Identification Mechanisms



Sensor Systems – Reporting Techniques



Components of (Bio) Sensors



Bio Sensor Systems

Environmental Sample

Readout

Collect → Prepare → Identify → Report → Analyze

Model (components & system)

- Model components and system.
- Optimize end-to-end performance.
- Understand limiting factors.
- Predict performance in new environments.

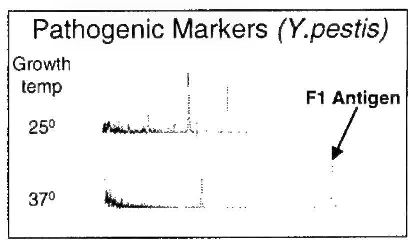
Characterize (sensitivity & specificity)

- Statistically significant P_D vs P_{fa}.
- Real environments (clutter, temperature, humidity…).
- Operational protocols.

Mass Spec Prototype Development

Hardware proof of concept

- Technology components:
  - MALDI ionization
  - TOF reflectron
- Successfully generates spectra of whole proteins.

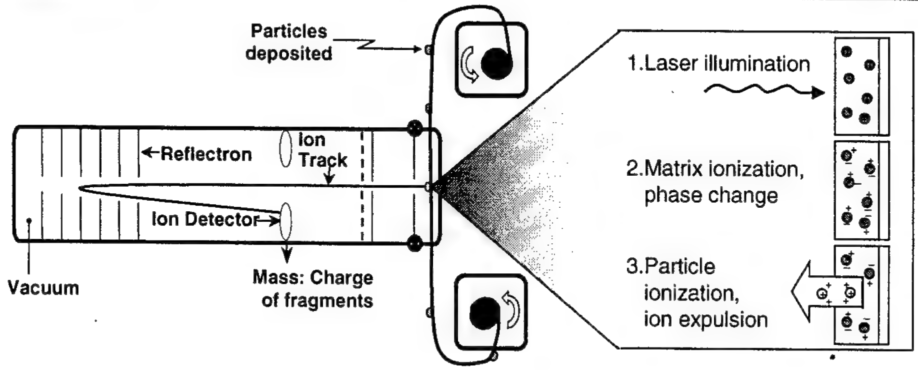


Systems Issues

- Agent signature library
- Stability of signature
- Instrument calibration
- Background signature characterization
- Signature quenching
- Algorithms for signature extraction
- Signature predictions
- Matrix modeling, optimization

Mass Spec Modeling

Special Projects Office

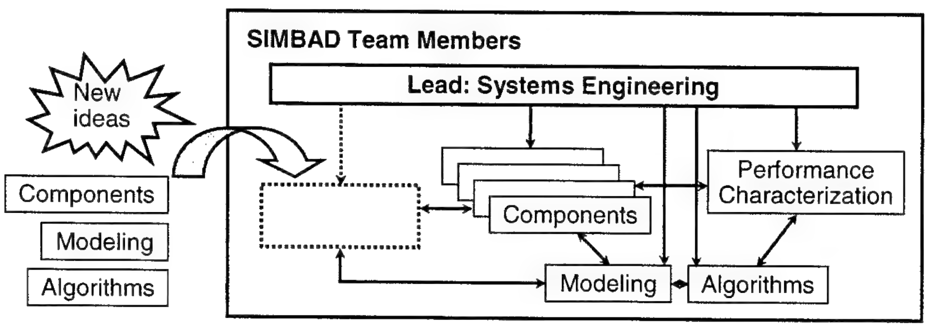


- Ionization process plays important role in system sensitivity and variability.
- Modeling effort is underway to guide system optimization, interpretation of output.

SIMBAD

Special Projects Office

- Purpose: To develop and demonstrate prototype advanced sensor systems that work. They must be:
  - optimized;
  - well characterized;
  - reliable.
- Approach: New "way of doing business":
  - No stovepipes.
  - Strong systems-engineering lead.
  - Broad technical expertise.
  - End-to-end development.



Contacts & Other Interests

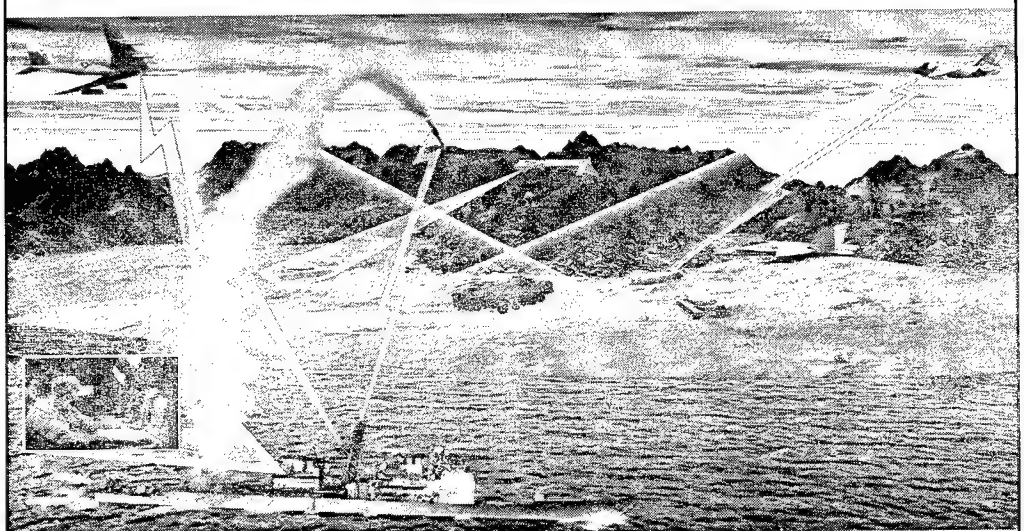
Contacts

- Office coordination — Amy E. Alving
- Building protection — tbd
- Sensors — Steve Buchsbaum, Millie Donlon

Other interests

- Bio surveillance systems
- Novel forensics
- Portal barriers for bio/chem
- Production detection

Networked Targeting Technology



Stephen Welby
Special Projects Office

Next Generation Time Critical Targeting

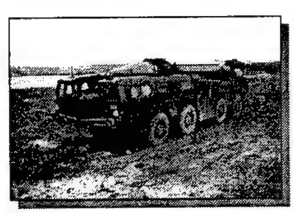
Future Battlespace Dominance *Requires* the Ability to Hold Opposing Forces at Risk:

- At Any Time
- In Any Weather
- Fixed, Stationary or Moving

Opponents Will Take Advantage of Delays or Shortcomings in US Quick Reaction Targeting Capabilities to Shelter Threat Systems

Examples:

- Use of mobility to protect threat surface-to-surface and surface-to-air missile systems
- Use of very short duration air defense emissions to avoid anti-radiation missile targeting



Key Enabler: Robust Tactical Networks

- Significant Investment Has Led to Widespread Planned Availability of Tactical Data Links
- This Investment Can Be Leveraged to Enable New **Rapid Reaction Targeting Concepts** Through the *Dynamic Synchronization* of *Sensors* and *Strike Weapons* Systems Across Large Areas over Tactical Networks
- Networked Targeting Offers Significant Advantages in *Precision* Over Traditional ISR and Traditional Stand-Alone Weapon Delivery Systems
- Networked Targeting Precision Supports:
  - Increased Lethality
  - Increased Effectiveness
  - Minimizes Collateral Damage
  - Minimizes Risk to US and Coalition Forces

The DARPA Special Projects Office is Aggressively Pursuing Networked Targeting

3

DARPA Special Projects Office Networked Targeting Programs

- **Affordable Moving Surface Target Engagement (AMSTE)**
  - Network Ground Moving Target Indication (GMTI) Sensors with Precision Weapons to Enable Precision, Stand-Off Engagement of Movers
  - Networked Targeting Permits:
    - Multi-Lateration of Stand-Off ISR and Strike GMTI Radars for Targeting Precision
    - Precision Tracking of Targets From Nomination through End Game with Targeting Updates to Weapons in Flight
    - Use of Low Cost GPS Guidance and Low Cost Seekers
- **Advanced Tactical Targeting Technology (AT3)**
  - Network Threat Warning Receivers to Enable Rapid, Precision Geolocation of Short-Dwell Emitters
  - Networked Targeting Permits:
    - Very Rapid Reaction Against Pop-Up Threats (seconds)
    - Extremely Precise Geolocation

4

The AMSTE Motivation

Special Projects Office

- Technology Investments Have Enabled US Forces to Hold Fixed and Stationary Targets at Risk
- AMSTE Will Extend US Battlefield Dominance to Moving Threats
  - **Extend our capabilities to permit all weather engagement of vehicles on the move**
  - **Deny opponents the sanctuary of movement**

- Existing Technologies Provide the Basis for the *Affordable* Precision Targeting of Moving Surface Targets
  - **Planned GMTI sensors**
  - **Precision weapons**
  - **Communication networks**
  - **High performance processing**

AMSTE is a systems-of-systems approach, coupling capable sensors to precision weapons through robust sensor-to-sensor and sensor-to-weapon networks

AMSTE Focus

Special Projects Office

Target *moving* surface threats from long range and rapidly *engage* with precision, stand-off weapons

Key AMSTE Characteristics:

***All-Weather Engagement*:**	**Requires use of multi-laterated, geo-registered GMTI sensors**
***Targeting Focused*:**	**Requires ability to maintain threat track from nomination through engagement**
***Precision Engagement*:**	**Requires ability to provide fire control updates to weapons in flight**

AMSTE Technologies support a seamless moving target engagement from Nomination ➠ Track Maintenance ➠ Engagement

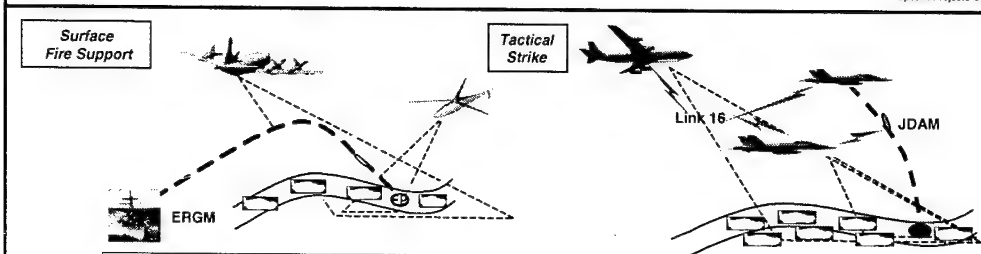
AMSTE Challenges

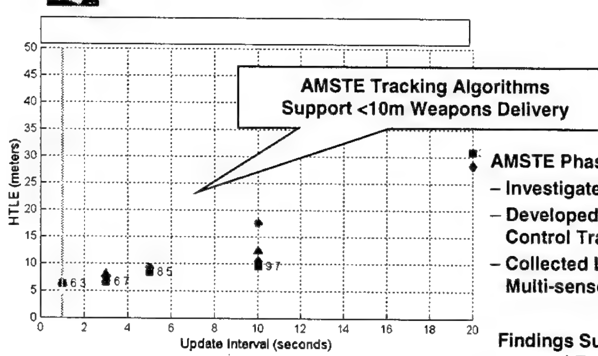
DARPA — SPO Special Projects Office

Issues	Approach
• *Track Accuracy*	Networking of Standoff/Penetrating Sensors GMTI Radar Multilateration Advanced Tracking Algorithms Grid-locking and Geo-registration
• *Precision Endgame*	In-Flight Weapon Target Updates Weapon Data Links Precision Fire-Control Tracking Low-Cost Seekers
• *Track Maintenance*	Feature Aided Tracking
• *Affordability*	Maximize use of existing resources and minimize the need for new systems

AMSTE I Accomplishments

DARPA — SPO Special Projects Office





AMSTE Phase I:
- Investigated Weapons System Trades
- Developed and Tested Precision Fire Control Tracking Algorithms
- Collected Live and Simulated Multi-sensor GMTI data

Findings Support Feasibility of AMSTE Concept and Establish Foundation for AMSTE II

AMSTE Program Schedule and Milestones

Special Projects Office

AMSTE I

Concept Exploration
(complete)

AMSTE II

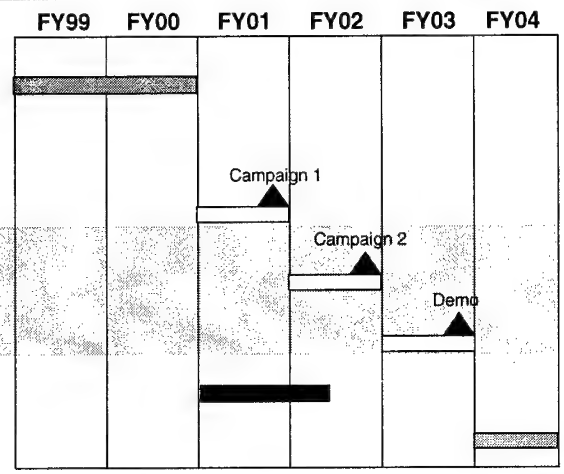
Precision Engagement

Track Maintenance and Precision Engagement

Integrated End-to-End System

Phenomenology for Feature Aided Tracking

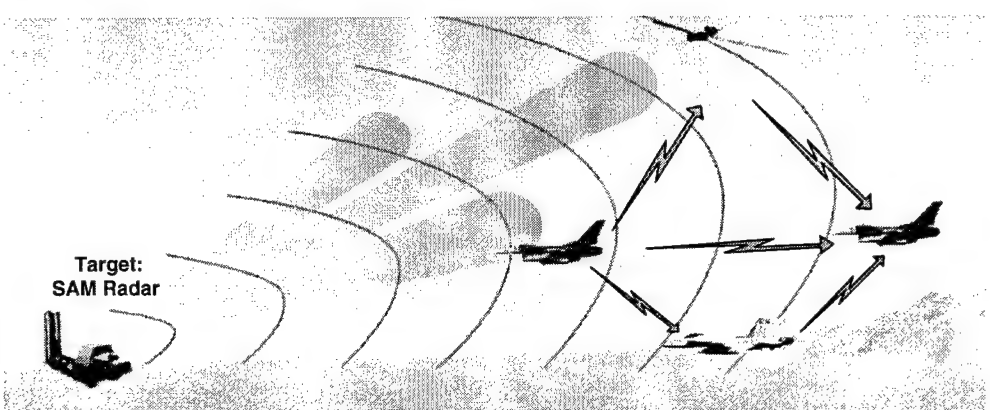
Service Demonstration



AMSTE II will use an Integrated, System-of-Systems Approach to Demonstrate an Affordable Moving Surface Target Engagement Solution

Advanced Tactical Targeting Technology (AT3)

Special Projects Office

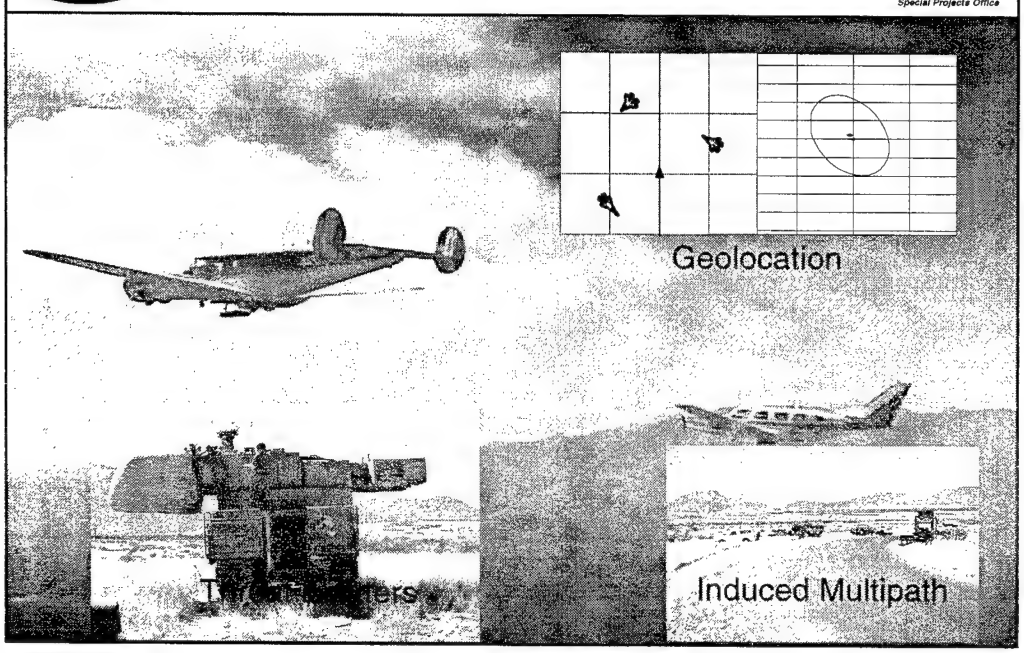


- **Very Rapid, Very Precise Emitter Geolocation**
- **Platforms of Opportunity – Highly Dynamic**

AT3 Challenges

Issues	Approach
• *Exploit Threat Sidelobe Emissions*	• Affordable, High Performance Digital Receiver
• *Common Pulse, Ambiguity Resolution, Geolocation*	• Exploit Correlations within Pulse Trains and Between Collector Platforms – Coherent vs. Non-coherent • 7-D Precise Registration of Battle Space
• *Network Management, Collector Cueing, Traffic Load Reduction*	• Network Simulation/Analysis Traffic Management/Data Compression • Novel, Transparent Tactical Network Approaches
• *Multipath, RF Agility, etc.*	• Leading Edge, Inter-Collector Multipath Decorrelation, Digital Receiver Flexibility, Other

AT3 Phase I



AT3 Phase II

Status

- Raytheon (Tucson, AZ) Proceeding to FY02 Data Collection and Real Time Flight Demonstration

Opportunity

- Innovative Multi-Ship Algorithm Development
  - Dense Pulse De-interleaving
  - Highly Agile Emitters
  - Coherent Techniques
  - Polarization Exploitation, etc.

- Explore Trade Space in Non-Real Time Environment

Tactical Networking Technology Opportunities

- Networked Targeting Can Be Limited By Tactical Network Capacity, Latency and Rigidity
  - The Need:
    - Increased bandwidth and on-the-fly reconfigurability
    - Very low latency data transfer
    - Advanced network planning/management
    - Compatibility with legacy systems

- New Applications for Tactical Networking Concepts
  - Synchronization of Strike and Sensor Assets for Real-Time Battle Damage Assessment

DARPA Special Projects Office
Networked Targeting Programs

- DARPA SPO Is Aggressively Pursuing The Networked Targeting Paradigm Through Advanced Applications Such as AMSTE and AT3
- Near Term Experimentation with Networked Targeting Must Involve Both Technologists and Users
  - Co-development of Advanced System Concepts and Supporting Tactics, Training and Procedures is Critical to Successful Transition of Networked Targeting Approaches
- Networked Targeting Approach Offers Promise In Many Other Mission Areas by Realizing Tighter Coupling Between Sensors and Shooters

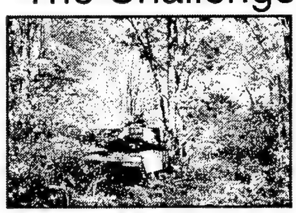
Counter Concealed Target Technologies

Mr. Lee R. Moyer
Special Projects Office

DARPATech 2000
6-8 September 2000

CC&D Tactics Pose A Challenge to U.S. Targeting Systems

The Challenge:



- Camouflage, Concealment and Deception techniques include:
  - Masking: Foliage cover, radar camouflage nets, chaff, weather
  - Tactics: Rapid movements between hide locations during deployment or after firing, emitting or over-flight
  - Decoys: Divert attention, generate false information

DARPA/SPOs objective is to develop technologies that effectively counter an adversary's use of CC&D

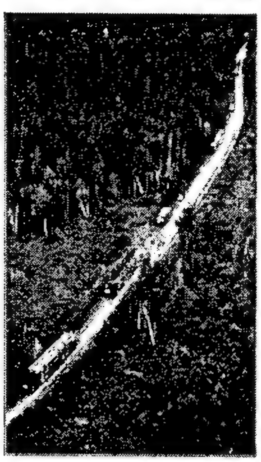
DARPA/SPO Is Addressing CC&D Tactics Through a Variety of Approaches

- Foliage Penetration (FOPEN) Synthetic Aperture Radar (SAR)
  - High-resolution, fully polarimetric imaging of stationary targets
- FOPEN Ground Moving Target Indication (GMTI) Radar
  - Moving target detection and tracking from airborne platforms
  - Low-cost, ground-based, bistatic radars to track vehicles and personnel in foliage
- Multi-Sensor Fusion
  - Fusion of FOPEN and microwave (μW) SAR and GMTI, ESM and spectral sensor data to enhance identification and reduce the false alarm rate
- Target Identification
  - Close-in sensor packages
  - Multi-look 3-D laser radar (LADAR) imaging

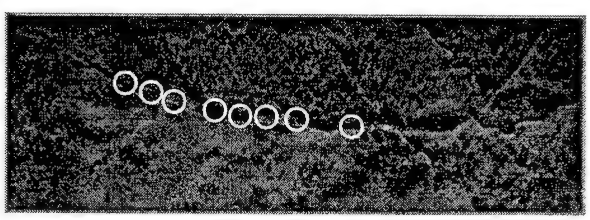
FOPEN Radar Denies an Enemy the Ability to Maneuver and Hide Under Foliage

Example of Foliage-Obscured Vehicles

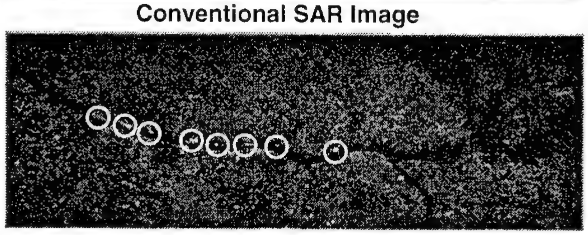
- Depression Angle: 45°, Resolution: 1 m x 1 m
- Vehicles Masked By Trees, Along Logging Road in Maine



Photograph



Conventional SAR Image

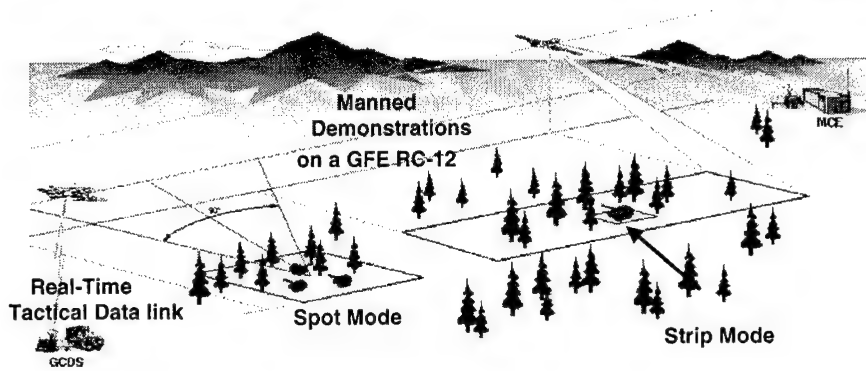


FOPEN SAR Image

DARPA/SPO Is Presently Developing a FOPEN SAR to Detect Stationary Targets

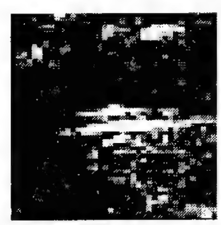
- The FOPEN SAR is a real-time dual-band system
  - Horizontally polarized VHF SAR for target cueing
  - Fully polarimetric UHF SAR for target discrimination and false alarm rejection
  - System being installed and tested on Army RC-12
  - Form, fit and function compatible with Global Hawk UAV

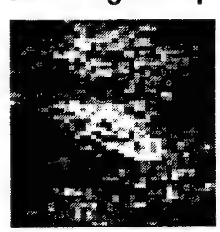

VHF Target Cue



FOPEN SAR: Challenges and Opportunities

- Automatic Target Detection and Cueing (ATD/C) algorithms
  - Enhance target detectability
  - Minimize false alarms
- Advanced processing algorithms
  - RFI suppression
  - Waveform optimization
  - Change detection
  - Target classification
  - Interferometry / stereo / tomography
- FOPEN SAR applications
  - Battle space characterization
  - Environmental monitoring
  - Terrain mapping

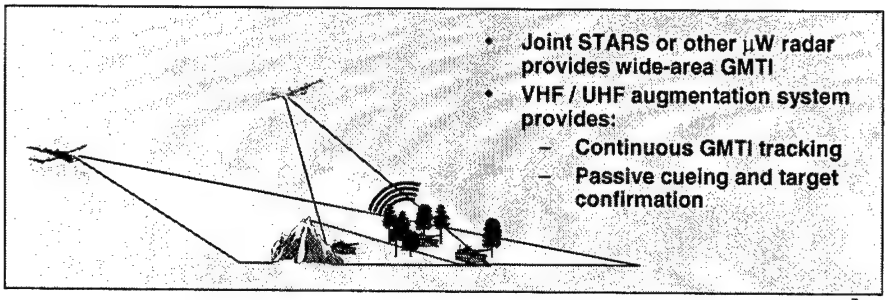

UHF Target Chip


UHF Clutter Chip

DARPA/SPO Is Assessing Integrated VHF / UHF GMTI Radar and ESM Technologies

Special Projects Office

- VHF / UHF GMTI radar provides all-terrain, all-weather capability
  - Track targets under foliage
  - Provide a high target position update rate
- Bistatic GMTI operation enhances system survivability
- Concurrent ESM uses allocated system resources to identify targets and locate emitters



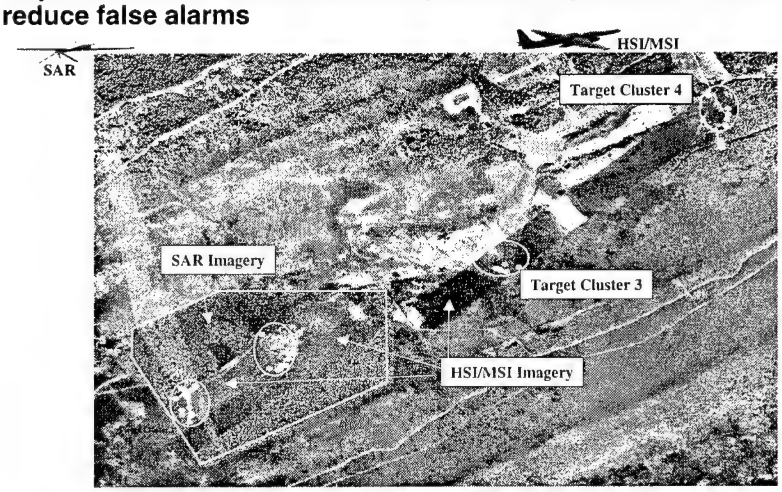
Integrated VHF/UHF System Technologies: Challenges and Opportunities

Special Projects Office

- System architecture
  - Monostatic and bistatic concepts
  - Deployment on UAVs and other suitable platform
  - Integration / utilization of GMTI radar and ESM
- Airborne hardware components
  - Transmitter, antenna, receiver and signal processor
- Adaptive, non-adaptive and ESM processing algorithms
- Concept of Operations (CONOPS)
  - Utilization of GMTI radar and ESM resources
  - Interaction with FOPEN SAR and microwave radars

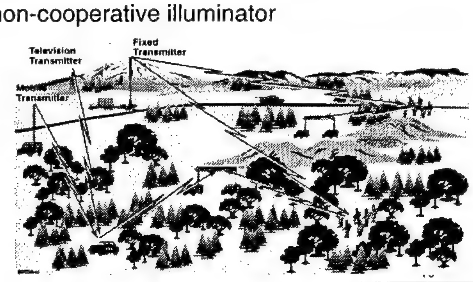
DARPA/SPO Is Assessing Multi-Sensor Fusion to Counter CC&D Tactics

- **Objectives: Enhance detections, perform target identification and reduce false alarms**



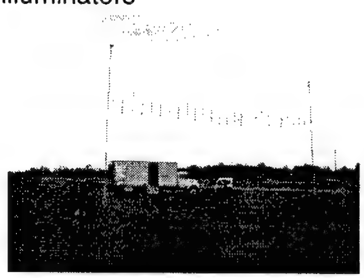
Ground-Based FOPEN GMTI Ground Radar

- Objective: Provide effective, low-cost force protection for ground units
  - Detect personnel / vehicles through foliage
    - Personnel detection to ranges of 4.5 km
    - Vehicle detection to ranges of 7 km
  - Use either cooperative or non-cooperative transmitter
    - Cooperative units could also provide communication / navigation functions
    - HDTV station could serve as non-cooperative illuminator
- Program goals:
  - High performance
  - Rapid deployment
  - Light weight
  - Low cost



Ground-Based FOPEN GMTI Radar Challenges and Opportunities

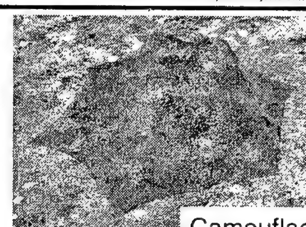
- Low-cost, light-weight antenna and receiver technologies
  - Wide tunable bandwidth
  - Rapid deployment
- Algorithms
  - Cooperative and non-cooperative illuminators
  - Adaptive processing
  - Tracking
- CONOPS
  - Emitter selection
  - Emitter functions
  - Deployment geometries



Proof-of-Concept System

Hard-to-Identify Targets

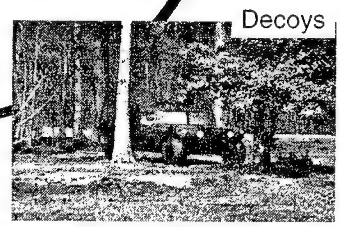
Foliage

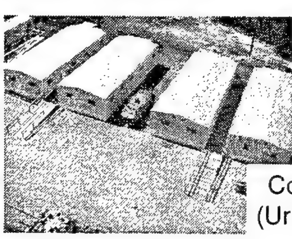


Camouflage

Approaches:
- Close-in sensor package
- LADAR for 3-D sensing
- Multi-mode sensing

Decoys





Complex Environments
(Urban, Clutter, Proximity)

Summary

- DARPA/SPO's goal is to develop and demonstrate viable Counter CC&D technologies and to transition them to the Warfighter
  - Currently addressing the detection of concealed targets through a variety of airborne and ground-based sensor efforts
  - Increasing emphasis is being placed on tracking (GMTI), identification and engagement
- DARPA/SPO welcomes the presentation of new and innovative concepts for surveillance, identification and engagement of stressing surface targets

DARPA Guidance/Navigation Technology

Lt Col Greg Vansuch
Special Projects Office

DARPATech 2000
6-8 September 2000

Guidance Technology Programs

MEMS INS

- Gyroscopes 1.0 to 10°/hr
- Accelerometers 500 mg
- ≤10 in³, ≤0.8 lbs

Global Positioning Experiments

- Airborne Pseudolite (APL)
  - Digital Beamforming Antenna
  - Software Only Modified GPS Receivers
  - Employ on UAVs

GPS Guidance Package (GGP)

- 12 Channel GPS Receiver (≤16 m SEP)
- Nav Grade INS (≤1nmi/hr)
- 170 in³, ≤10 lb, 25-30 W, ≤$15K

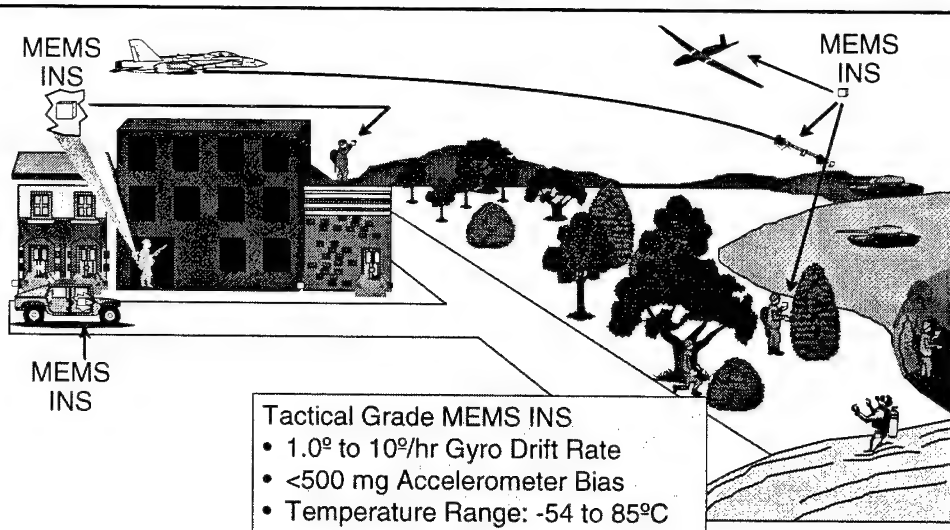
Guidance Technology

- Advanced Navigation Concepts
- Innovative Technologies
- Affordability
- Warfighter Applications

Motivation

- GGP Lowers Cost, Improves Reliability and Improves Performance of Tightly Coupled GPS/INS Navigation
  - Surface to Surface Projectile Launchers (MLRS, HIMARS), Aircraft (F/A-18, Apache), Surface Navigation (M1A2, AAAV), Long Time of Flight Missiles (Tomahawk)
- Tactical Grade MEMS INS Enables Many Applications
  - Inertial Munitions, Personal Inertial Navigation, Personal Underwater Navigation, Micro-Air Vehicles, Tactical Missiles, Unmanned Aerial Vehicles, Sea/Land Vehicle Sensors
- GPX Pseudolites Provide an Augmentation to GPS Signals Under Conditions of Jamming
  - First Launch of L_M Capable Satellite is 2008 or Later
  - IOC for Block IIF Satellites is 2016
  - At Least 10-15 Years Benefit from Airborne Pseudolites

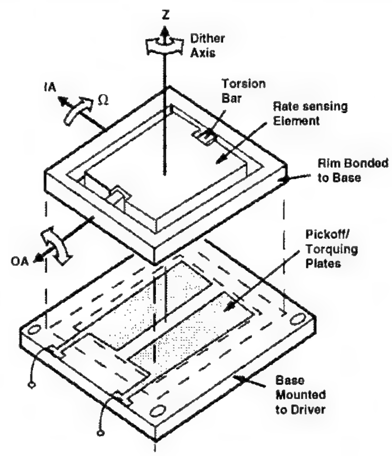
Micro-Electromechanical System (MEMS) Inertial Navigation System (INS)



Tactical Grade MEMS INS
- 1.0º to 10º/hr Gyro Drift Rate
- <500 mg Accelerometer Bias
- Temperature Range: -54 to 85ºC
- Low Power: <3 Watts
- Small Size: <10 cu inch

Current MEMS INS Gyroscope Designs

•Litton—Silicon Gyroscope (a conceptual example)



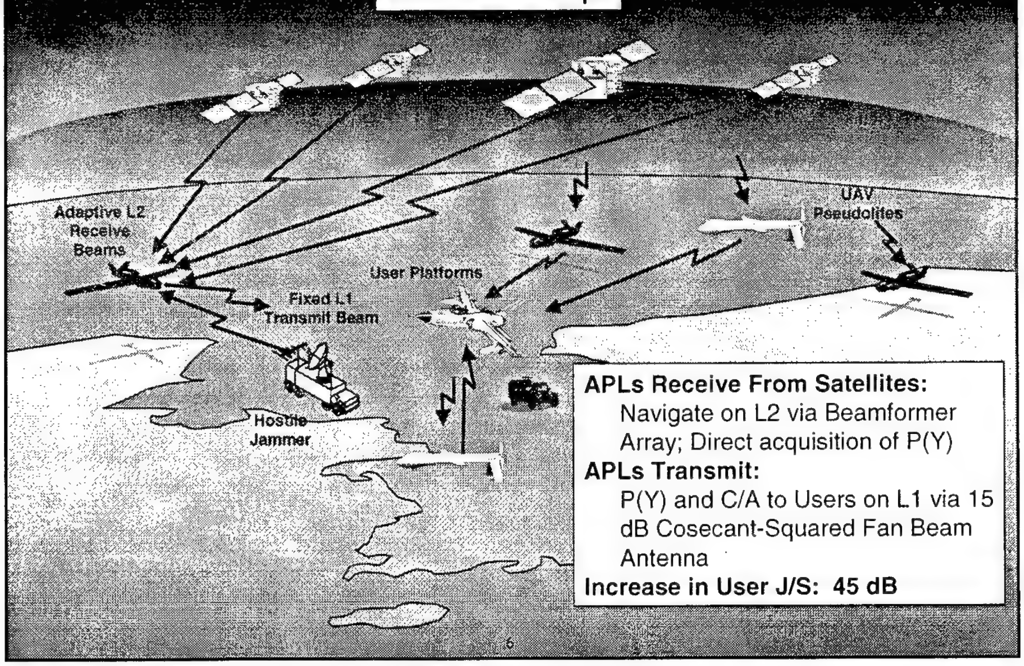
Principle of Operation

- Coriolis Force Sensors
- Measure platform rotation (**W**) around Input Axis (IA)
- Dither device around Dither Axis (z) to produce **v** and –**v** on opposite sides
- Sense Coriolis rotation around Output Axis (OA) using pickoff plates

$$\mathbf{F}_{\text{Coriolis}} = -2\, m\, \Omega \times \mathbf{v}$$

- Draper--Tuning Fork Gyro (TFG)
- Kearfott--Micromachine Vibrating Beam Multisensor (MVBM)

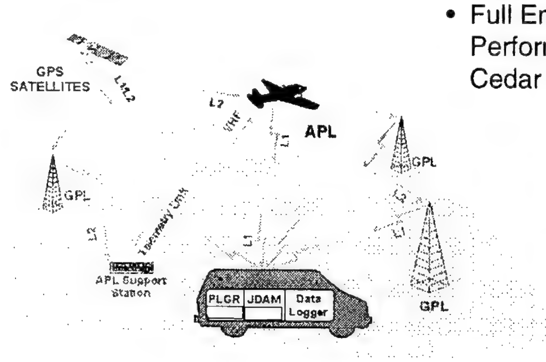
GPX Concept



APLs Receive From Satellites:
Navigate on L2 via Beamformer Array; Direct acquisition of P(Y)
APLs Transmit:
P(Y) and C/A to Users on L1 via 15 dB Cosecant-Squared Fan Beam Antenna
Increase in User J/S: 45 dB

First Flight Demonstrations (GPX)

Special Projects Office



- First Airborne Pseudolite (APL) Broadcast (9/99)
- Full End-to-End APL/GPL/UE Performance Demonstrated Live in Cedar Rapids, IA (11/99)
  - 3 GPLs Located on Fixed Towers
  - One APL on Sabreliner Commercial Jet
  - Handheld PLGR GPS Receiver and JDAM GPS Receiver Located in Moving Van
  - Demonstrated and Assessed Geolocation Performance in a Variety of Static and Dynamic Scenarios; User Receivers Operated Without GPS Satellites

Successful Navigation Demonstration

Demonstrated Range Error of 4.36 m (Original Estimate 4.5m; Goal 10m)

UAV Flight Demonstration

Special Projects Office

When

April 2000

Where

Fort Huachuca, AZ

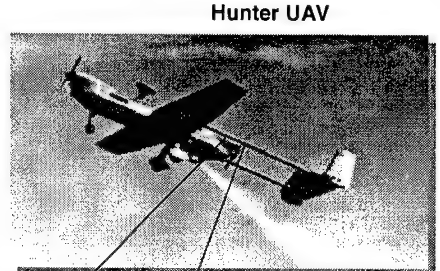
What

Demonstrate APL Effectiveness against GPS Jamming

Results

- Modified PLGR, JDAM worked in jamming
- Unmodified PLGR jammed

Hunter UAV

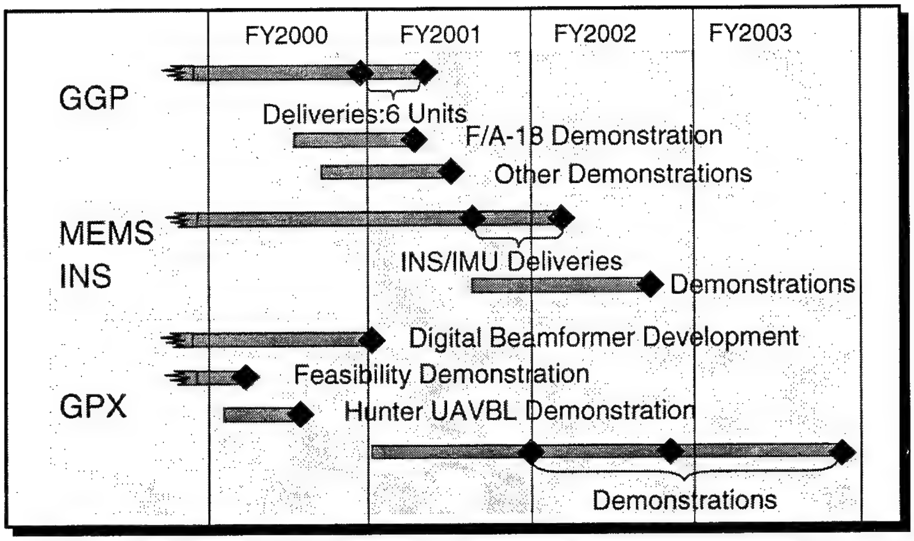


Boom Pod

- **Air Force UAV Battlelab and DARPA Funding**

Successful Navigation in Jamming

Guidance Technology Schedule



Conclusions

- GGP
  - Potential F/A-18 and MLRS Demonstrations
- MEMS INS
  - Laboratory Results Indicate Progress Toward 1-10°/hour Over Military Environment
- GPX
  - Successful Feasibility Demonstrations Completed
  - Demonstrations of Beamformer, Transmitter, Transparency, Multiple Platforms, and Live Fire Being Planned
- New Ideas?

Multifaceted, Innovative
Navigation and Guidance Technologies
for the Warfighter

DSO

Defense Sciences Office

Michael J. Goldblatt

Director

mgoldblatt@darpa.mil

http://www.darpa.mil

DARPA

DSO

Mission

"Technology Harvesting"

Identify and vigorously pursue the most promising technologies within the science and engineering research communities and develop them into new DoD capabilities.

DARPA

DSO — In Practice

- **Respond to technological opportunity**
- **Emphasize a *multidisciplinary* technical approach**
- **Recognize defense / commercial *industry as customer***

DSO — Personnel

Director, Dr. Michael J. Goldblatt
Deputy Director, Dr. Steven G. Wax

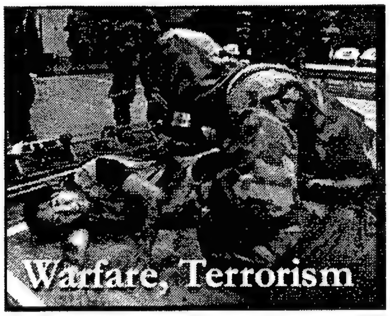
Materials, Mathematics and Devices

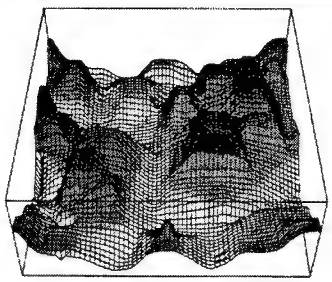
- Dr. Valerie Browning
- Dr. Leo Christodoulou
- Dr. William Coblenz
- Dr. Ephrahim Garcia
- Dr. Dennis Healy, Jr.
- Dr. Robert Nowak
- Dr. William Warren
- Dr. Stuart Wolf

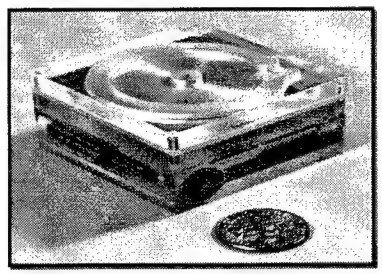
Advanced Biological and Medical Technologies

- Dr. Robert Carnes
- Dr. Eric Eisenstadt
- Dr. Kurt Henry
- Dr. Stephen Morse
- Dr. Alan Rudolph
- Dr. Wallace Smith

Technology Thrusts –Program Synergy



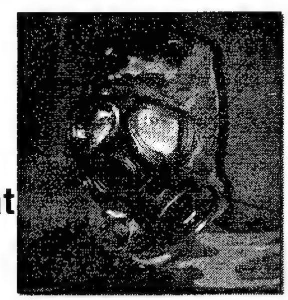


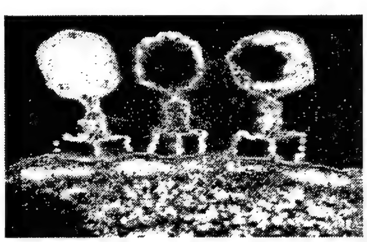


DARPA

Biological Warfare Defense

- Medical countermeasures
- Advanced diagnostics
- External protection
- Consequence management
- Genomic sequencing

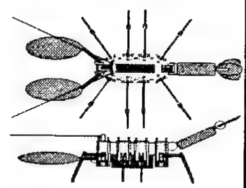


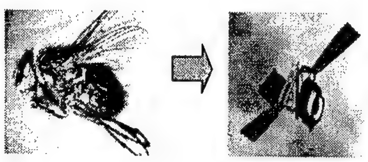


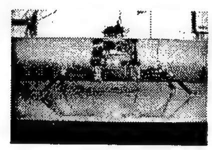
DARPA

Biology

- Cell and tissue-based biosensors
- Controlled biological systems /Bio-inspired systems
- Fundamental research at the [BIO:INFO:MICRO] interface

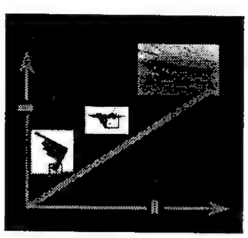


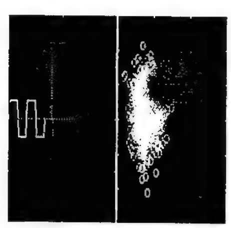


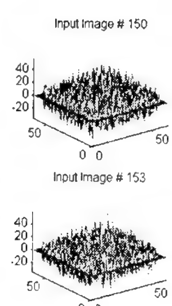


Advanced Mathematics

- Signal and Image Processing
- Virtual Electromagnetic Test-range
- Physics-based Design for Materials Processing
- Scalable Strategies for Scientific Computations

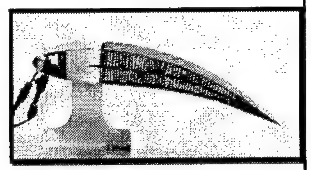


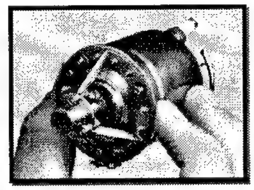


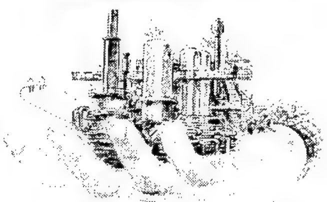


Materials and Devices

- Functional materials and devices
- Smart materials and demonstrations
- Structural materials and components
- Mesoscopic machines
- Power generation and storage







Developing New Ideas

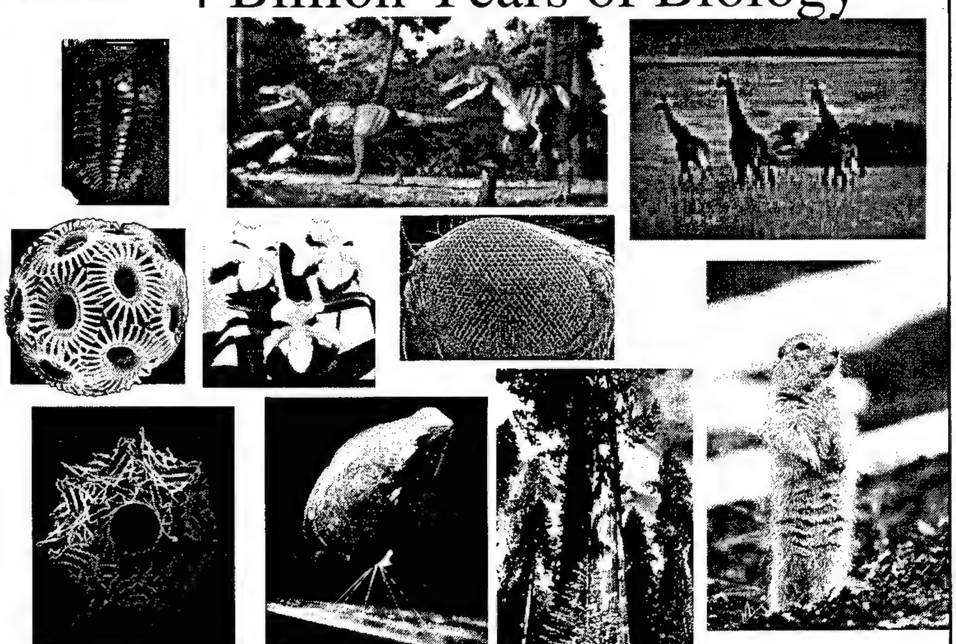
- Materials Prognostics and Asset Readiness
- Quantum Information Science and Technology
- Biological Gears and Motors
- Performance Enhancement
- Digital Maps and Sensory Systems
- Biotechnology
- Activity Detection Technologies
- Meta Materials
- Living Machines

http://www.darpa.mil/DSO/solicitations/

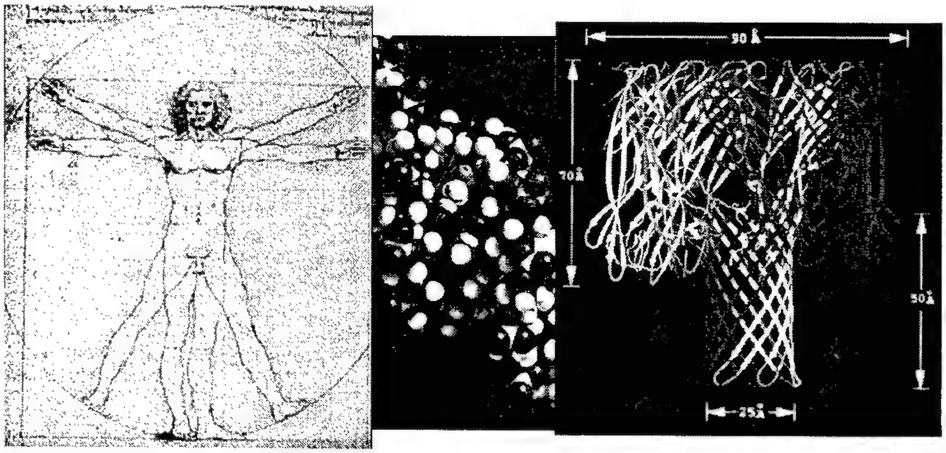
Why and How DARPA/DSO Does Biology

Eric Eisenstadt

4 Billion Years of Biology



~50 Years of Molecular Biology



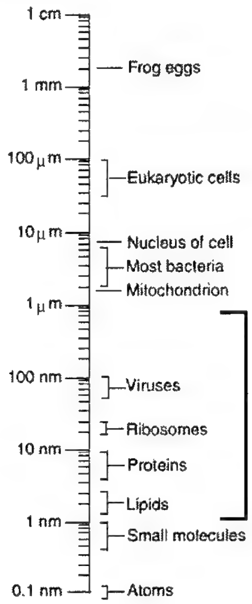
•1953: Structure of DNA

•2000: Human genome sequence

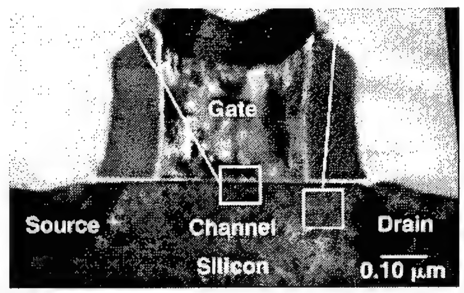
Improved DOD Capabilities via Biology

•Health
•Operations
•Materials synthesis

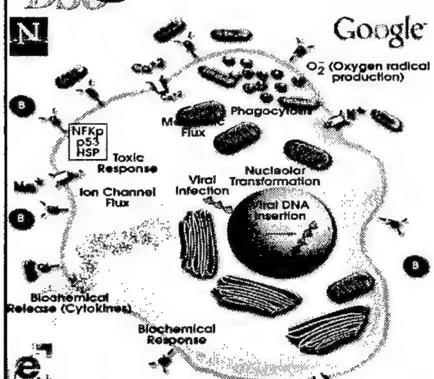
Physical Maps to Bio



CMOS elements



Info Maps to Biology



MEKVDIFKDIAERTGGDIYLGVVGAVRTGKSTFIK
KFMELVLPNISNEADRARAQDELPQSAAGKTIMT
TEPKFVPNQAMSVHVSDGLDVNIRLVDCVGYTVP
GAKGYEDENGPRMINTPWYEEPIPFHEAAEIGTRK
VIQEHSTIGVVITTDGTIGDIARSDYIEAEERVIEEL
KEVGKPFIMVINSVRPYHPETEAMRQDLSEKYDIP
VLAMSVESMRESDVLSVLREALYEFPVLEVNVNL
PSWVMVLKENHWLRESYQESVKETVKDIKRLRD
VDRVVGQFSEFEFIESAGLAGIELGQGVAEIDLYA
PDHLYDQILKEVVGVEIRGRDHLLELMQDFAHAK
TEYDQVSDALKMVKQTGYGIAAPALADMSLDEP
EIIRQGSRFGVRLKAVAPSIHMIKVDVESEFAPIIGT
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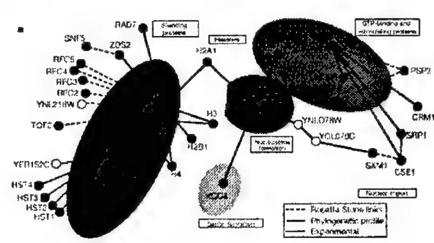
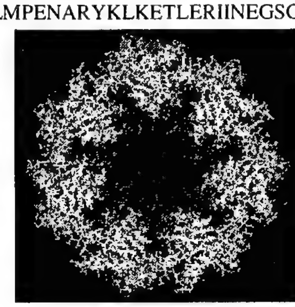
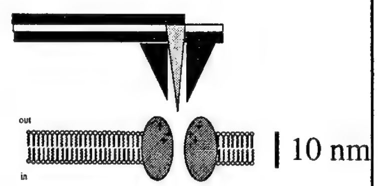
REGIQAKLSLMPENARYKLKETLERIINEGSGGLIA
IIL





Deciphering Biology

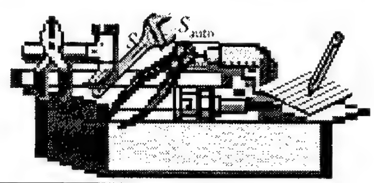
- Interrogate and manipulate biological systems with modern physical devices



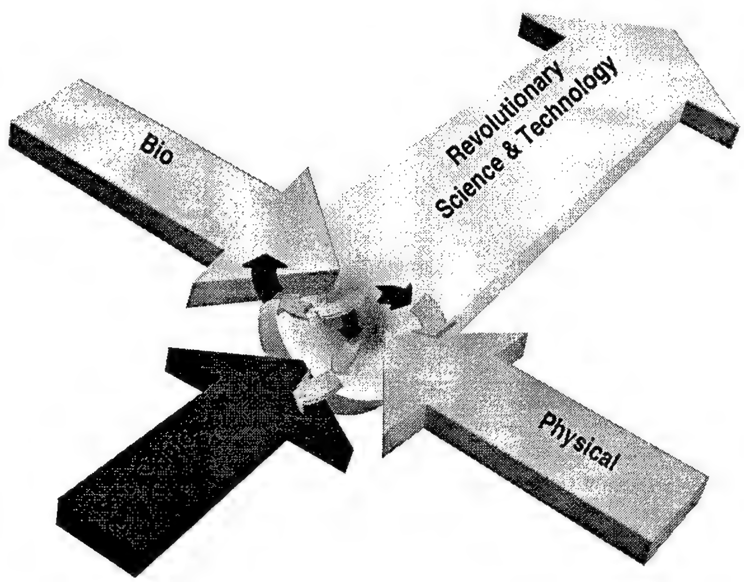
- Analyze, model and simulate with the full arsenal of math and computational tools

$$S_{unreg} = f'_{unreg}(R^*) = -k_{deg}$$

$$S_{auto} = f'_{auto}(R^*) = -\frac{nk_pPk_1ak_r}{(1 + k_pP + k_rR^*)^2} - k_{deg}$$



[Bio:Info:Physical]

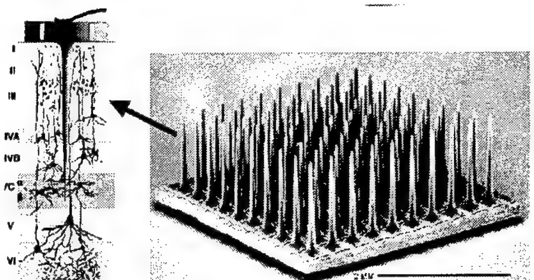


DARPA's Bio:Info:Physical Program

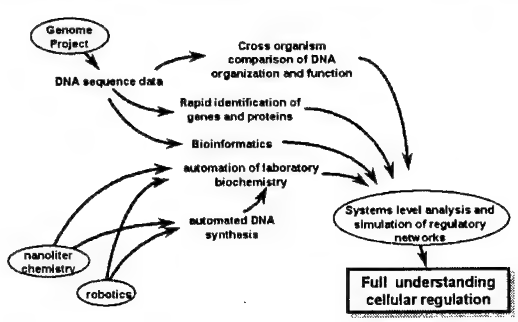
- First phase of DARPA BioFutures
- Fundamental research at universities
- Interdisciplinary
- Attack fundamental limits of understanding complex biological systems via the development and application of new devices and new information tools

Two Major Themes

- **Neuroprocessing and neurocontrol via high density implantable MEMS devices**
- **Measuring and modeling the dynamic behavior of biological regulatory networks in living cells**

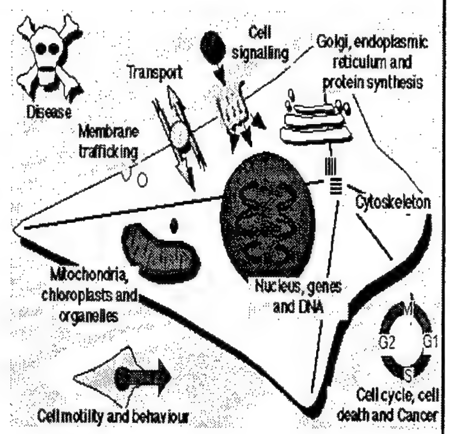


Courtesy Bionic Tech. Courtesy Bionic Tech.



The Cell is a High Information Content Sensor!

- Cell is unit machine in biology responsible for systems level processing
- Cells respond to environment in specific, reproducible and redundant ways
- Cell sensors do not require specific identification of threat
  - Processing will result in identification
  - Amplification of response
- Response is predictive of functional consequences



Tissue Based Biosensors Program Concept

CBW Threat → Physiological Biosensor → Human Health Risk Assessment

seconds → minutes → hours → days → years

• Is it chem or bio? • Live vs. dead? • Classification • Known or unknown	• Physiological consequences of exposure? • Functional response and mechanism of action?	• Long-term consequences of exposure? • Genotoxicity? • Human performance deficits?

DSO

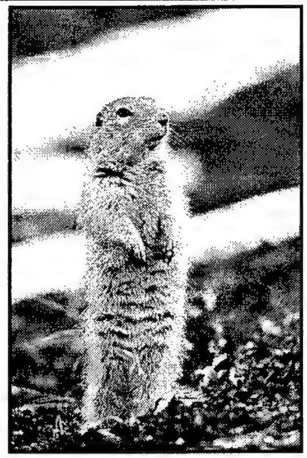
Nature's Metabolic Engineering

You've got questions?

We've got answers…

Performance Specs

- **37° to -5° C Core temps.**
- **Heart rate: 300 to 7 bpm**
- **CBF: down to 7% of norm.**
- **BMR down to <10% of norm.**
- **94% genetic homology with humans**



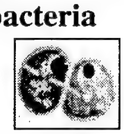
Arctic Ground Squirrel

DSO

Natural Examples of Metabolic Control and Downregulation

Exploit the lessons learned from "Life on the Edge"

Extremophile bacteria



Dried *Tardegrade*

Frozen frog

Hibernating squirrel

10^{-6} 10^{-3} 10^{-2} 10^{-1}

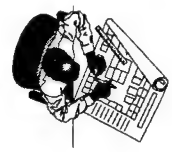
meters

Why now?

- <u>Recent discoveries</u> in stasis strategies, genetics, and gene products now enable the development of a metabolic strategies and systems "toolbox".

Sequencing Pathogen Genomes

- A genome sequence is a cell's blueprint



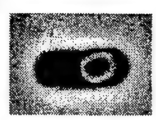
- Annotating a genome sequence yields the identity of its unique and common molecular parts

- Knowing the molecular parts permits rational design of countermeasures and detection strategies

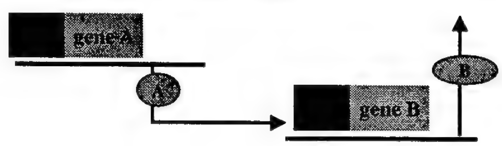
A New Era in Biology, a New Era for DARPA

- Molecular anatomy

- Where the parts are



- How the parts work as a system



DARPA's role will be to develop not only new understanding but, more importantly, new biologically inspired systems, tools and devices that enhance DoD and national security

Semiconductor Spintronics Electronics for the 21st century

Stuart Wolf

Semiconductor Spintronics

Objective

To create a revolutionary new class of semiconductor electronics based on the spin degree of freedom of the electron in addition to, or in place of, the charge.

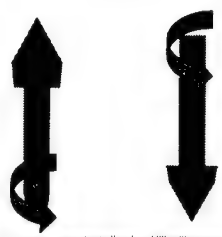
Rationale for Spintronics

Conventional Electronics ⟶ Charge

- Based on number of charges and their energy
- Performance limited in speed and dissipation

Spintronics ⟶ Spin

- Based on direction of spin and spin coupling
- Capable of much higher speed at very low power



Spintronics Challange

In March of 1959, Richard Feynman challenged his listeners to build

> **"Computers with wires no wider than 100 atoms, a microscope that could view individual atoms, machines that could manipulate atoms 1 by 1, and circuits involving quantized energy levels or the interactions of quantized spins."**

Richard Feynman - "There's Plenty of Room at the Bottom"
1959 Annual Meeting of the American Physical Society

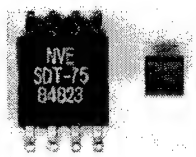
Spintronics

Magnetoresistive thin films and nanostructures are already extremely important scientifically, technologically and economically.

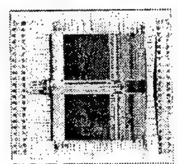
- Economics: -Today
  - Magnetic recording alone is a $100 billion/yr

The IBM Travelstar disk drive
uses magnetoresistive devices to achieve 4.1Gb/in^2

  - Tomorrow – Potential additional $100 billion/year



Sensors-Isolators



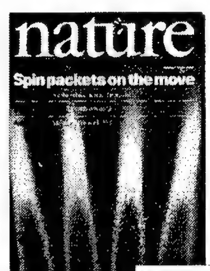
Non-Volatile
Radiation Hard
High Density
Very High Speed
Low Cost

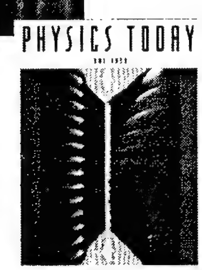
Magnetic RAM

Spins IN Semiconductors

New Direction-SPINS

- Two recent discoveries
  - Optically Induced long lived coherent spin state in semiconductors
  - Ferromagnetism in semiconducting GaMnAs above 120K (Sendai, Japan 1998)

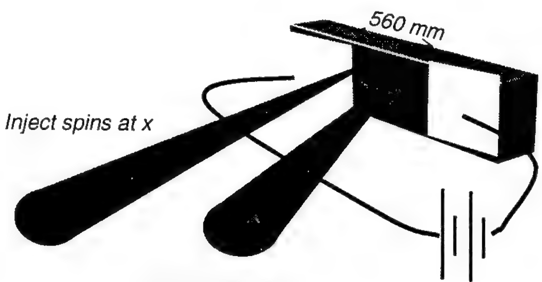


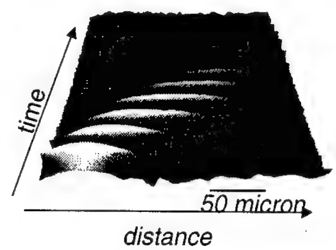


- Will lead to revolutionary advances in 21st Century photonics and electronics such as:
  - Very high performance opto-electronic devices
  - Very fast, very dense memory and logic at extremely low power
  - Spin quantum devices like Spin-FETs, Spin LEDs and Spin RTDs
  - **Quantum computing in conventional semiconductors at room temperature**
  - Many other applications that we can't even envision now

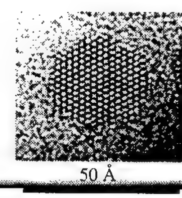
Injection and Motion of Coherent Spins in Semiconductors

- Spin coherence persists for 100s of nanoseconds over 100s of microns
- Largely insensitive to temperature





- *Spin coherence also demonstrated in CdSe Quantum Dots*
- *Room temperature operation with nanosecond lifetimes*

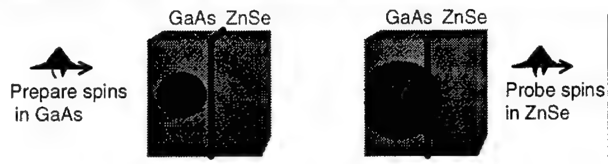


Enabler for Quantum Computation

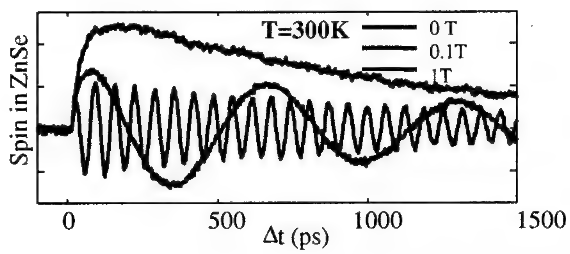
What Needs to be Done

- Since spin effects in semiconductors are largely ***unexplored*** it will be essential to
  - Explore ways to raise Curie temperature of magnetic semiconductors
  - Explore optical and transport properties which offer new spin dependent avenues
    - **Understand and control interface effects and spin transport across interfaces**
  - Demonstate spin coherent optical devices
  - Demonstrate spin quantum devices
  - Demonstrate quantum logic with 8 qubits or more at or near room temperature

Spin Transfer Through Heterointerfaces



- Flow of coherent information across a heterointerface with dissimilar materials with very little scattering



UCSB

Spin Enhanced and Enabled Electronics

Quantum Spin Electronics

- Tunneling/transport of quantum confined spin states: natural frequency scale given by spin splitting: GHz-THz
- Spin dependent resonant tunneling diodes and spin filtering
- Spin FETs ("spin gating")
- Spin transistors
- Spin LEDs, electroluminescent devices, and spin Lasers

Coherent Spin Electronics

- Optically generated coherent spin states and coherent control of propagating spin information - optical encoders and decoders
- Directly generated coherent spin state and coherent control of propagating spin information

Quantum Information Processing

- Qubits using coherent spin states in quantum dots – quantum networks

Quantum Semiconductor Spintronics

Classical Bit (Boolean) *0 or 1* *Two states*

Quantum Bit (Qubit) $\alpha|0\rangle + \beta|1\rangle$ *"Infinite" number of states*

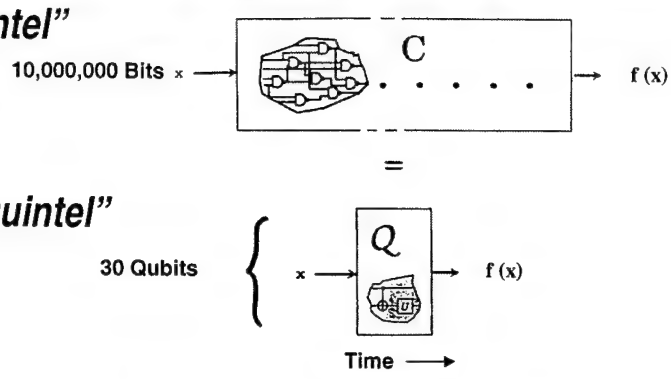
Where $(\alpha^2 + \beta^2) = 1$

$|0\rangle$ $|1\rangle$ $\alpha|0\rangle + \beta|1\rangle$

Quantum Spintronics

"Intel"

"Quintel"



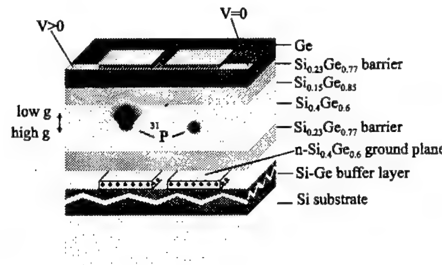
Factoring: *Given integer* ***N****, find integers* ***p*** *and* ***q*** *such that* ***N=pq****.*
Exponential Speedup: $2^{N^{1/2}} \longrightarrow N^2$

Optimization*: Given algorithm for computing a function* ***g****, find input* ***s*** *such that* ***g(s)*** *is minimal.*
Quadratic Speedup: $2^k \longrightarrow 2^{k/2}$

Quantum Spintronics

Qubit Implementations

- ➢ **Electron-Spin Resonance Transistor (ESRT):**



- ➢ **Long Dephasing Times (msec)**
- ➢ **High Switching Speed (GHz)**
- ➢ **Uses Silicon Technology And quantum dot expertise**

UCLA

I predict that there will be SPINS in your future

DARPA's ADVANCED ENERGY TECHNOLOGIES

DARPATECH 2000

Dr. Robert J. Nowak
DARPA/DSO
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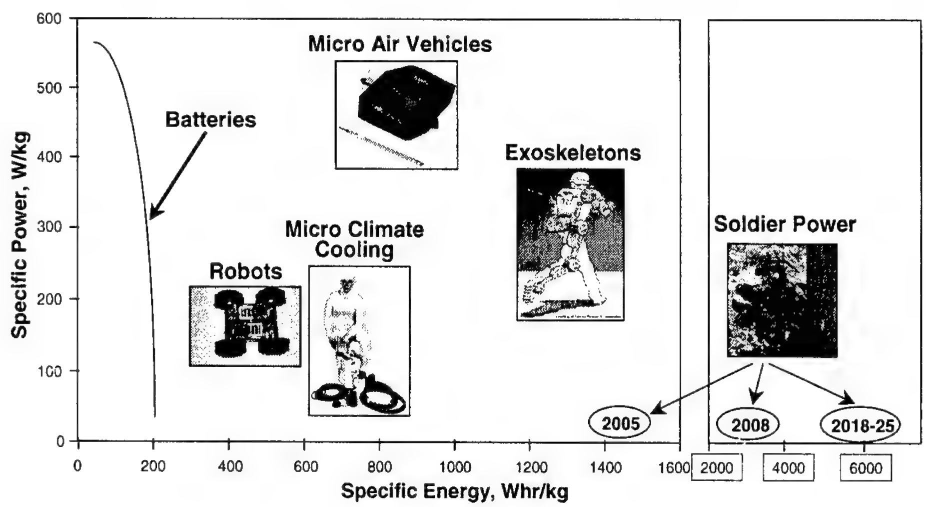
(703) 696-3999 (fax)
RNOWAK@darpa.mil

Advanced Energy Technologies Overview

- **Energy Conversion Strategies to Meet Portable Energy Shortfalls**
  - **Near-term Demonstrations**
  - **New Opportunities**
- **Energy Harvesting for Low-Power/ Long-Endurance Missions**
  - **Near-term Demonstrations**
  - **A New Breakthrough - Opportunity**

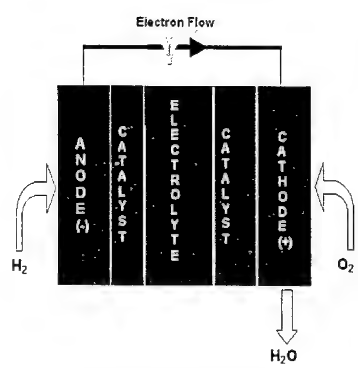
Performance Shortfall for Today's Power Sources



RNOWAK 08SEP00

Energy Conversion Technologies Considered For Portable Power Applications

Electrochemical $\varepsilon \sim 100\ \%$
- Fuel Cells



Heat Engines $\varepsilon = [(1 - T_L/T_H) * 100]\ \%$

Dynamic Systems
- Piston
- Turbines
- Stirling

Static Systems
- Thermoelectrics
- Thermionics
- Alkali Metal Thermal to Electric Conversion
- Thermophotovoltaics

Fuel cells promise earliest but not only opportunity

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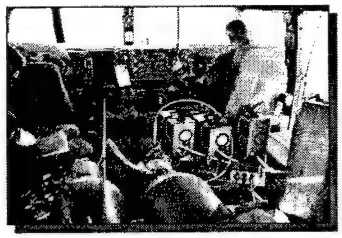
Marine Corps Air Ground Combat Center
29 Palms, CA, Fall 1999

TRAINING


Fuel Cells aboard Humvee


PRC-119 Radios

MILITARY EXERCISE


Retransmission Site

COST ESTIMATE FOR ONE DAY, ONE RETRANS SITE

- BA5590 BATTERIES = $900
- FUEL CELLS = $26

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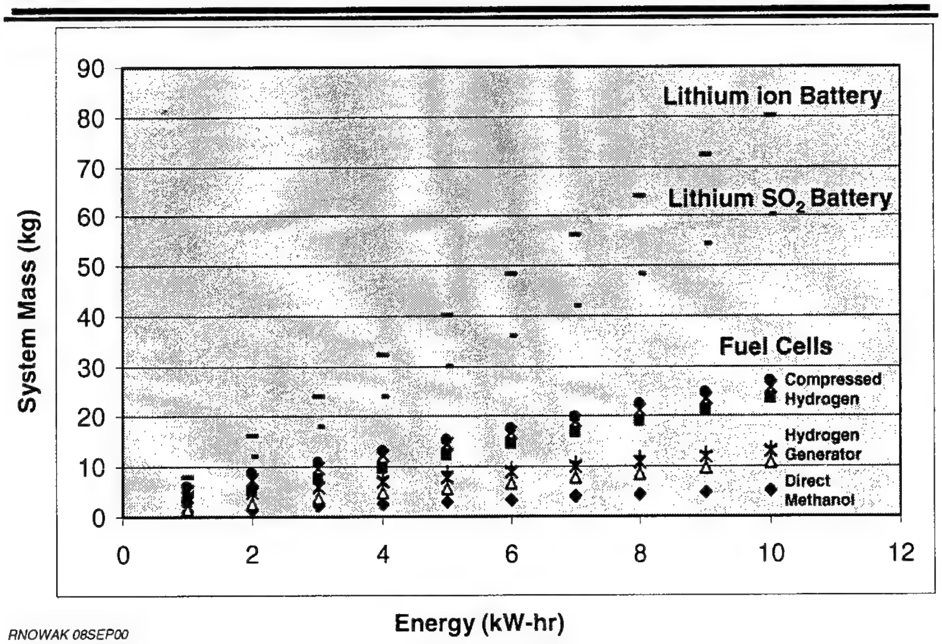
Lithium Battery / Portable Fuel Cell Comparison



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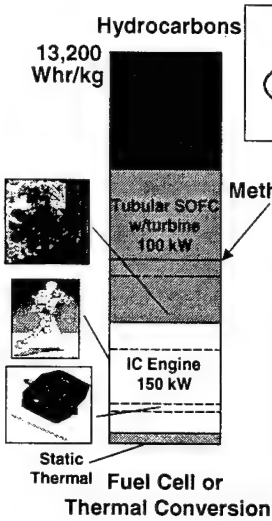
The Holy Grail? - *Direct* Conversion of Hydrocarbon Fuels

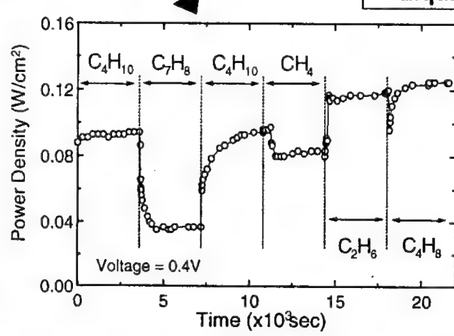


DIRECT OXIDATION

Liquid Fuel → Fuel Cell

CHALLENGES

- Increase Performance
  - → Catalysts
- Thermal management
- Liquid Fuels



Gorte, University of Pennsylvania

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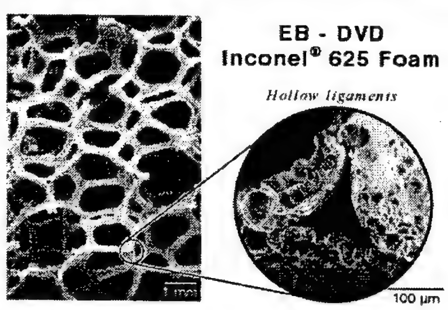
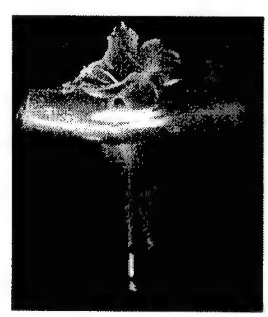
Thermal Management Opportunities

Superthermal Conductors and Heat Exchangers



Aerogel Insulators



K_{solid} Aerogel = 0.002 W/mK @ 300K
K_{solid} Silica = 1.4 W/mK @ 300K

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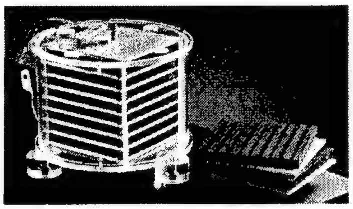
Thermal Integration Opportunities

Cascading Systems

- Thermally integrate multiple technologies
  - Design
  - Fabrication



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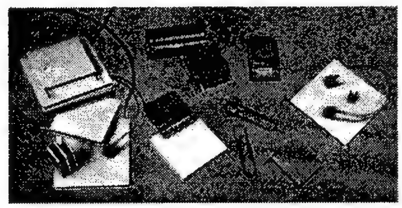


SOLID OXIDE FUEL CELL
1000 - 650 C

THERMOELECTRICS
1000 - 100 C

Integrated Efficiency >> Σ Individual Efficiencies

Energy Harvesting for Low-Power/Long-Endurance Missions

Technical Goal

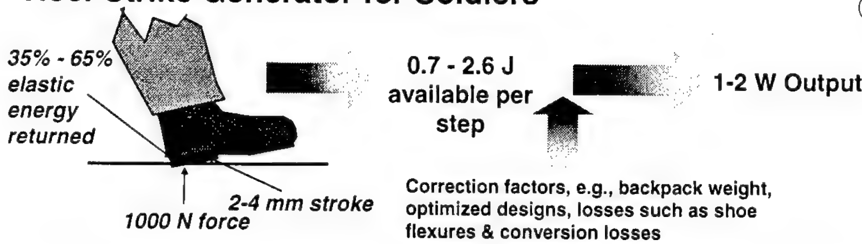
- Significantly increase mission endurance (>10x) for soldiers and sensors

Technical Approach

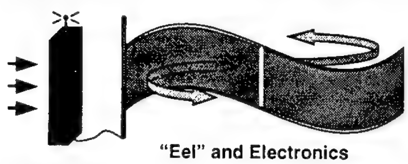
- Harvest energy and fuel from environmental sources
- Integrate harvesting system with devices

Mechanical to Electrical Energy Conversion

Heel-Strike Generator for Soldiers

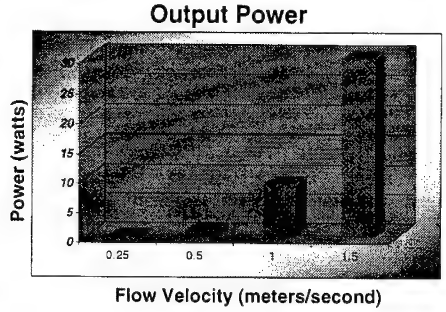


Energy Harvesting Eel for Undersea Power Generation



Ocean Power Technologies, Inc

Output Power



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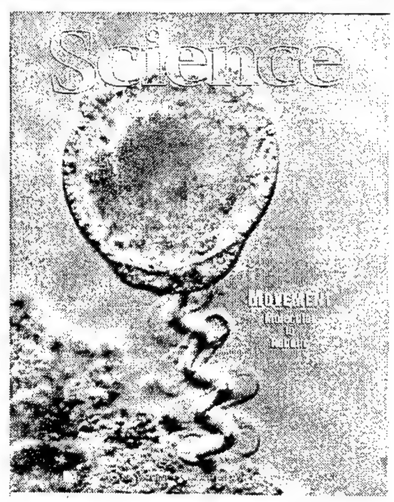
Fundamental Breakthroughs

November 1999 Rotary Motor Structure and Architectures



April 2000 Motor Proteins and Motion Systems Structure

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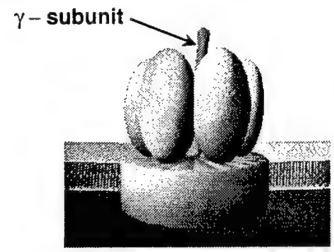
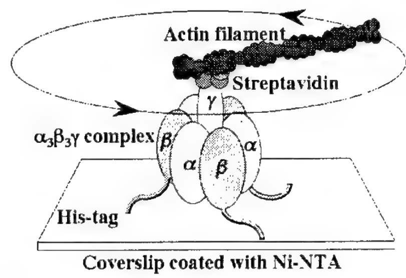
F_oF_1-ATPase Biomolecular Motor

Membrane-bound F_o-F_1 ATP Synthase



ATP → ADP + Pi → AMP + Pi



F_1-ATPase Biomolecular Motor with Actin Filament System (from Noji *et. al.* 1997)

- Ubiquitous enzyme
- Synthesize and hydrolyze ATP
- F_1 portion can act independently
- Gamma subunit of F_1 portion rotates (up to 17 r.p.s.)
- F_1 portion can generate up to 100 pN·nm torque

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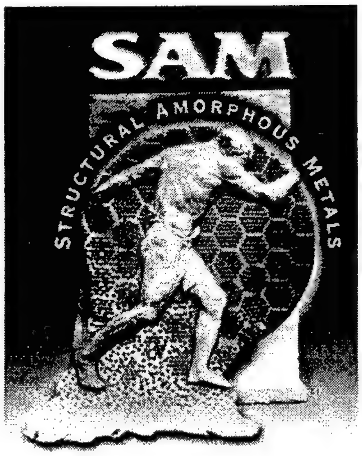
Biomolecular Motors

Technical Issues

- **Determine and Apply Critical Engineering Steps Toward Biomotor Devices**
  - Spatial and orientational control of motor elements at interfaces
  - Systems analysis of force production and work output (ATP in, work out), lifetime and robustness
- **Design, Build and Test Prototype Devices which utilize the ATP and Biological Motors**
  - Microvalves, pumps, fluidic movement, sensors and actuators, controlled release devices, robotics, ATP engines

RNOWAK 08SEP00

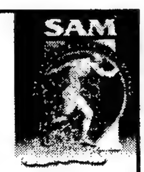


Structural Amorphous Metals

Leo Christodoulou

DARPA/DSO

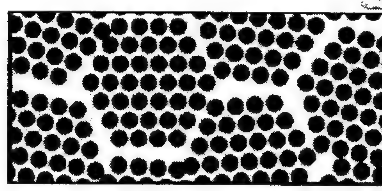
Compelling Opportunity



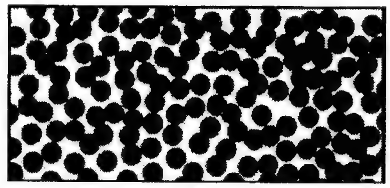
- **A totally new class of materials has been discovered with a radical combination of properties**
- **There are unique, compelling and enabling applications in several key DoD areas (e.g., ship hulls, aircraft structures, penetrators, etc.)**
- **DARPA will have a program to develop the science and technology of this field, and demonstrate its utility in example challenge problems**

Amorphous Metals are Fundamentally Different from Conventional Metals

Crystalline (Normal) Metals
- *Long-range order*
- *Grain boundaries*



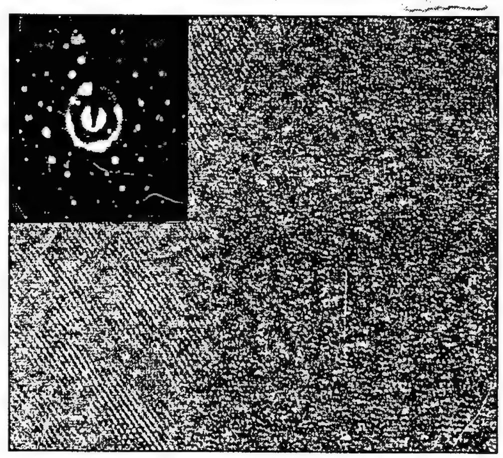
Amorphous Metals
- *NO long-range order*
- *NO grain boundaries*



Amorphous materials exhibit unique properties

Atomic Arrangement in Crystalline and Amorphous Metals

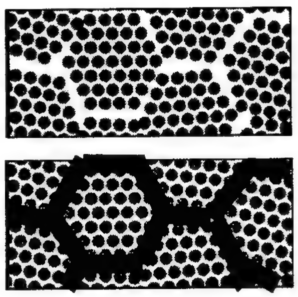
- Micrograph shows:
  - ➢Interface between amorphous and crystalline metal
  - ➢Atomic planes of crystalline metal
  - ➢Random arrangement of amorphous material
  - ➢Diffraction information



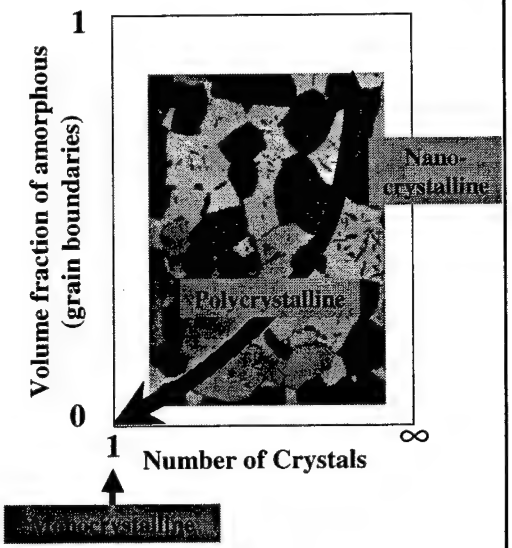
Crystalline ⟷ Amorphous

Since Their Discovery Metals have Relied on the Same Microstructural Constituents for their Properties

Polycrystalline

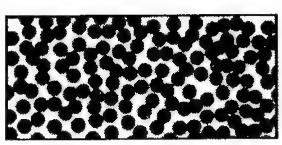


- Intersections of grains (grain boundaries) can be considered as "amorphous."
- Changes in grain size change the volume fraction of amorphous content

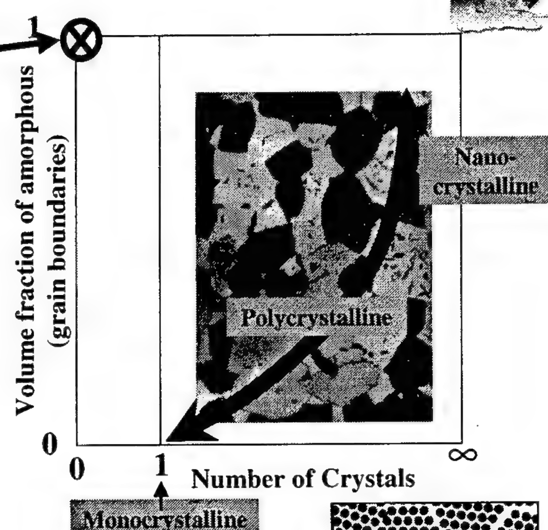


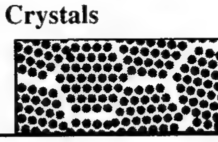
Structural Amorphous Metals Are New-to-the-World

Amorphous



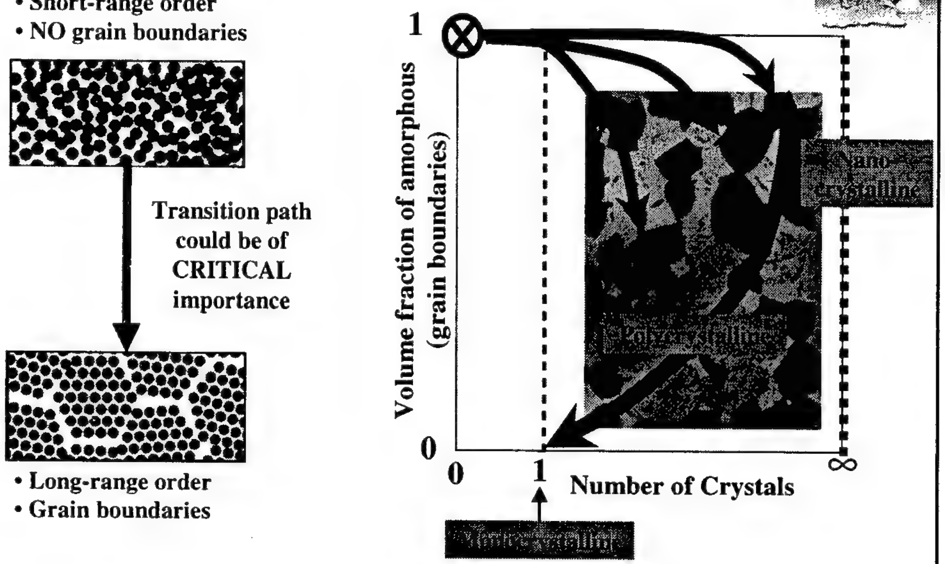
- Amorphous Metals are NOT confined by limitations of crystalline materials
- Such an opportunity has NOT previously existed for structural materials.





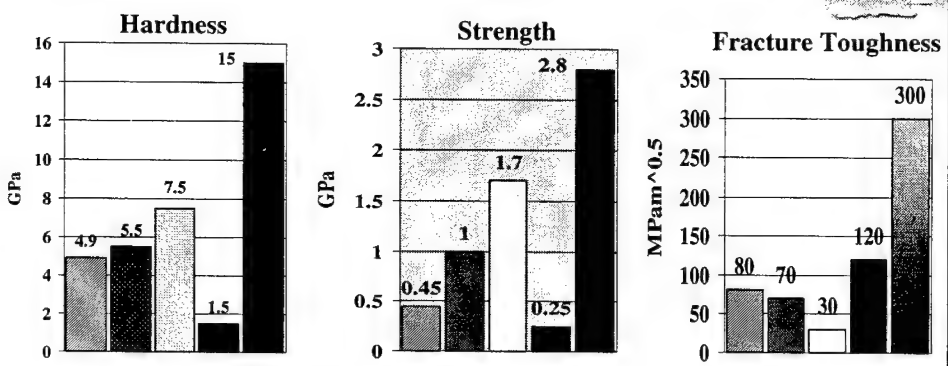
Transformations from the Amorphous to the Crystalline State Offer Unprecedented Materials Design Freedom

- Short-range order
- NO grain boundaries



- Long-range order
- Grain boundaries

Why Amorphous Metals?



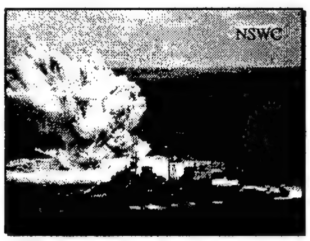
Steels

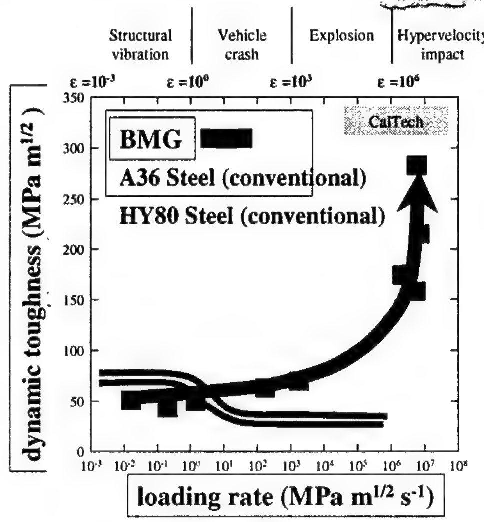
Carbon
High Strength
Tool
Stainless
Amorphous

Amorphous Metals are in a Class of their Own!

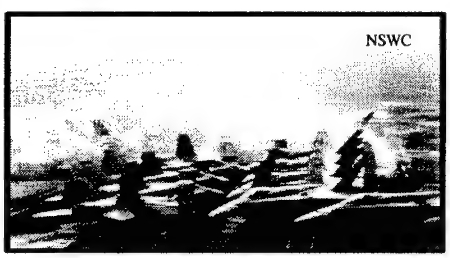
New-to-the-World Structural Materials: Unexpected Strain Rate Response in SAM

- Dynamic toughness of SAM is <u>EXACTLY</u> the opposite of conventional materials -- toughness increases with strain rate
- <u>Speculate</u> that combination of high strength, hardness and dynamic fracture behavior will translate into useful naval and other structures





Wear and Corrosion



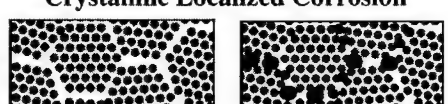
<u>Challenge Problem:</u>

Environmental conditions, e.g., marine environments, often induce degradation of properties due the presence of discontinuities within the material microstructure

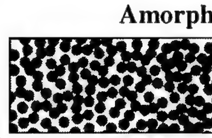
Amorphous Materials:

- Do NOT have grain boundaries (no corrosion initiation sites)
- Exhibit high wear resistance (better than Si_3N_4)
- Are damage tolerant

Crystalline Localized Corrosion

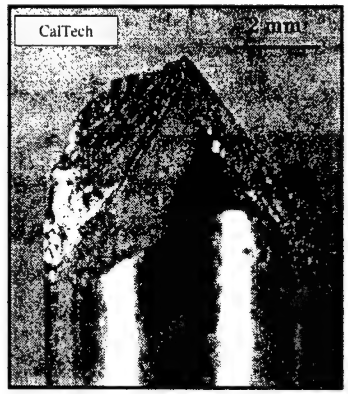


Amorphous Steel



???

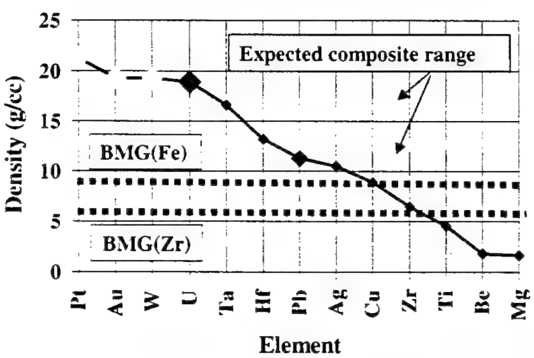
Amorphous Metals as New Penetrator Materials



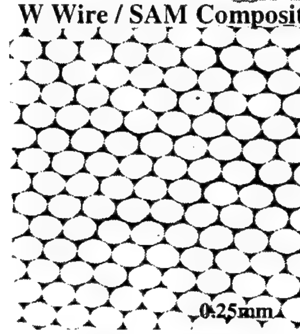
SAM materials known to exhibit self sharpening behavior

Penetrator Materials: Amorphous Metals Provide New Options

Need control of strength, toughness, elongation, density and self-sharpening behavior.



W Wire / SAM Composite



W V_f=80%,

ρ =16.8 g/cc

To achieve high density SAM must be turned into a composite.
ρ_{DU} = 18.9 ρ_{BMG}= 5.9-8.0g/cc. Tungsten is the obvious choice
Monolithic SAM may be sufficient in some applications.

Molecular Electronics (Moletronics)

William L. Warren, DARPA – DSO

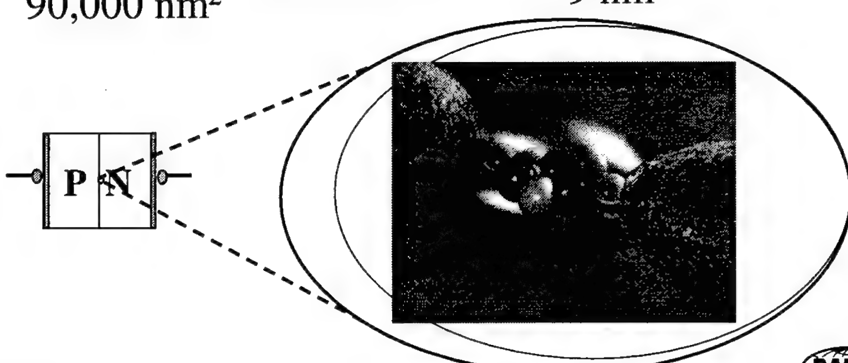
Christie R. K. Marrian, DARPA - MTO

Moletronics – What's It All About?

Replace conventional components with self-assembled functional molecules

P-N Diode → Molecule

90,000 nm^2 → 9 nm^2



Information Content

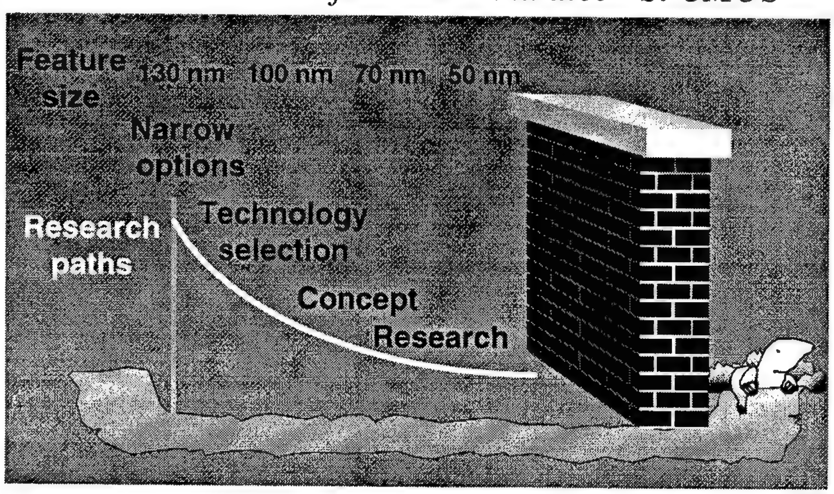
- One color photo ~ 10^5 b
- Average book ~ 10^6 b
- Genetic code ~ 10^{10} b
- Human brain ~ 10^{13} b
- Annual newspapers ~ 10^{14} b
- Library of Congress ~ 10^{15} b
- Human culture ~ 10^{16} b
- Annual television ~ 10^{18} b

Total ~ 10^{20} bytes

Imagine if we had a mole (> 10^{23}) of bytes!!

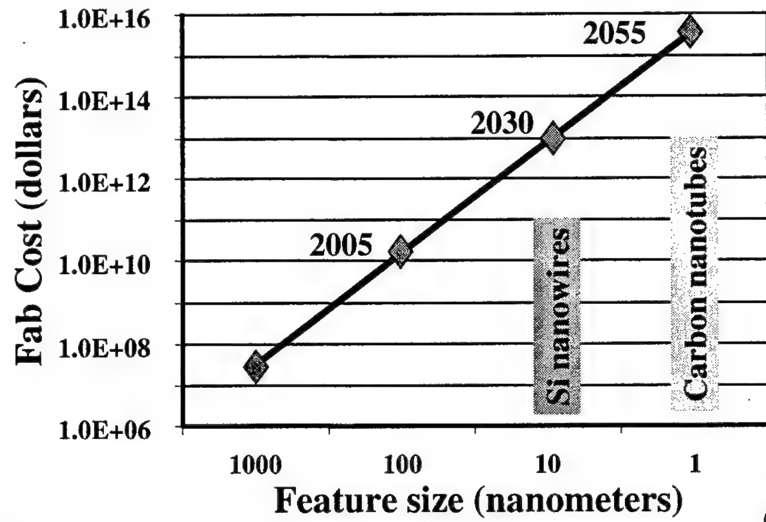
Moletronics – An Underground Operation

Technical hurdles for "slice and dice" Si CMOS



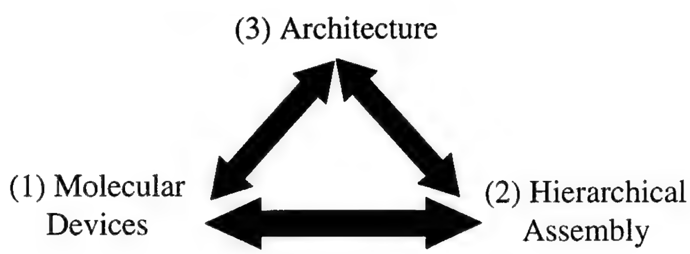
Moletronics Overcomes Fabrication Costs for Lilliputian Computers

Moore's First Law vs. Moore's Second Law

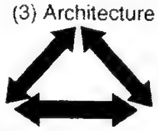


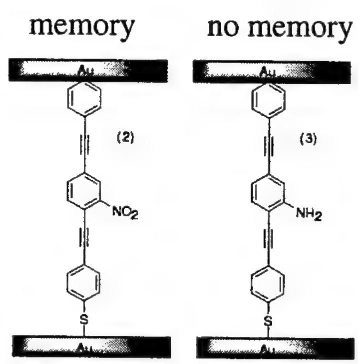
Moletronics: Re-Inventing the IC at Molecular Densities

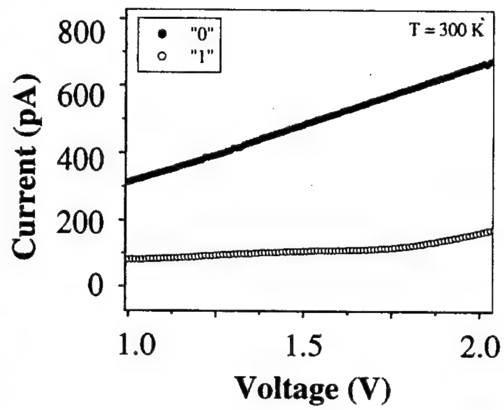
- **<u>Goal</u>**
  - Demonstrate computational functionality and I/O in ***scalable*** molecular systems using hierarchical assembly at insanely high device densities
- **<u>Moletronics Approach</u>**



The Need to Chemically Design Electronic Functionality





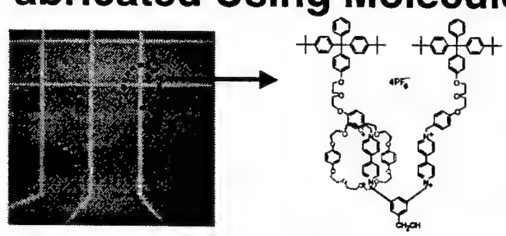


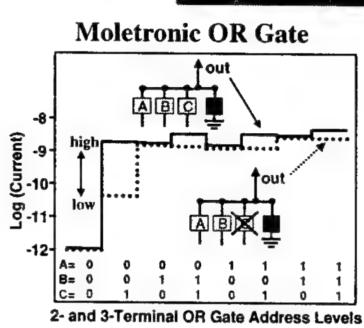
Yale University, Rice University

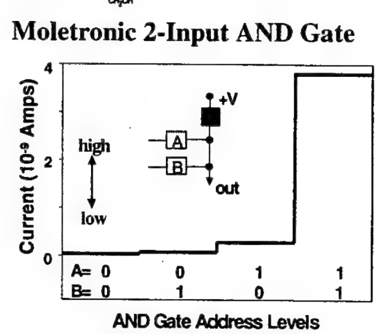
DARPA Tech 2000 Mole

DARPA

"OR" and "AND" Gates Have Been Fabricated Using Molecules







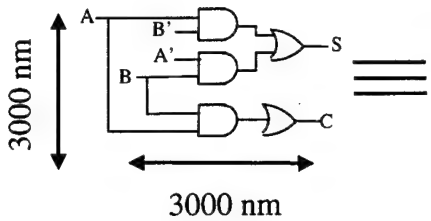
UCLA, HP Labs

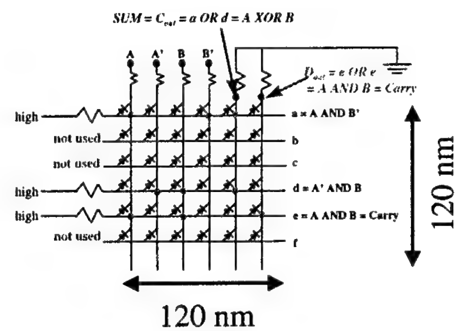
DARPA Tech 2000 Mole

DARPA

Mountains Into Molehills

Conventional Si | *Moletronics*

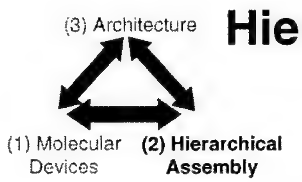




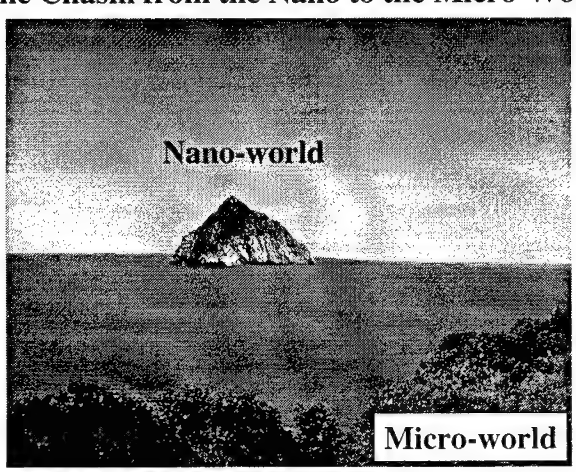
Logic gates ~ 3 transistors

10 nm lines, 20 nm pitch

Hierarchical Assembly

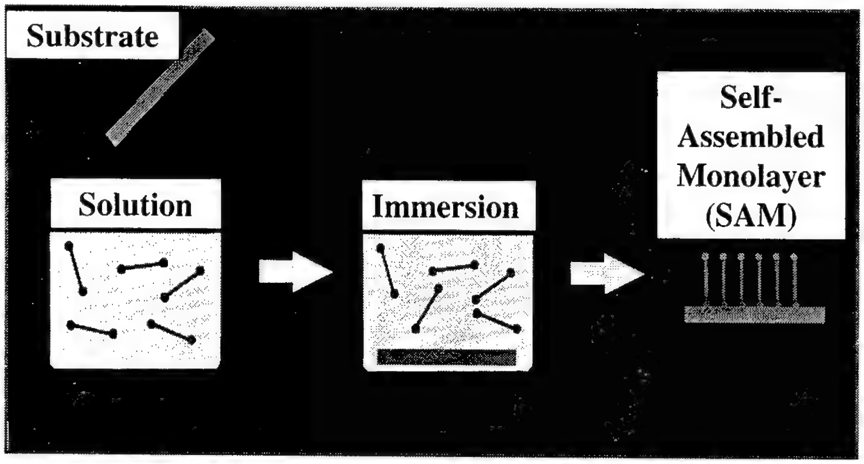


Crossing the Chasm from the Nano to the Micro-World



Self-Assembly

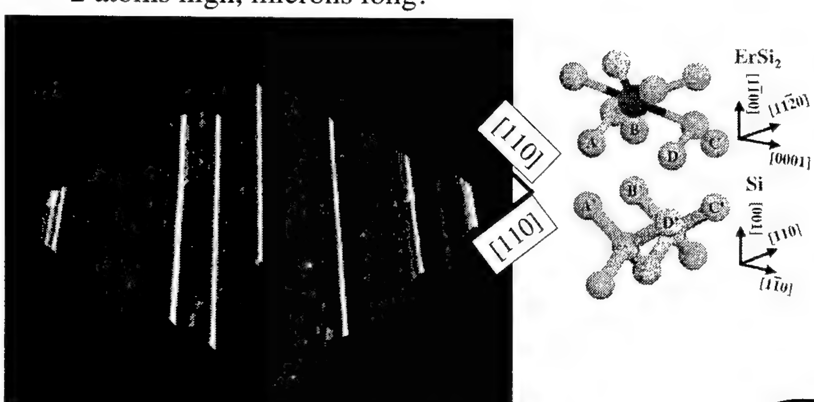
Process in which structures naturally assemble into desired patterns based on thermodynamic equilibrium



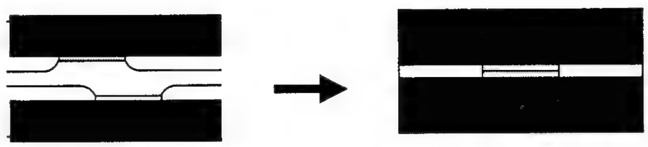
Self-Assembly Makes Aligned Arrays of 2 nm Nano-Wires

Assembly dictated by anisotropic lattice mismatch with Si

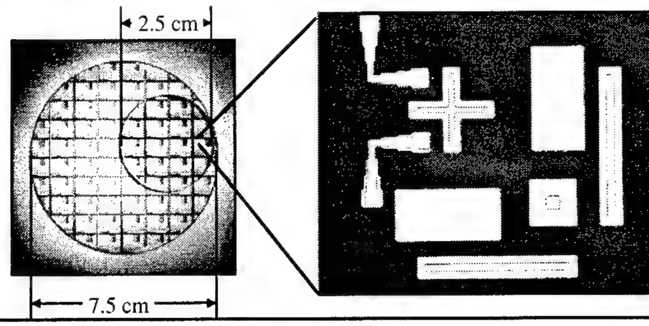
Unbelievable – 10 atoms wide,
2 atoms high, microns long!



Assembly of Cross-Bars Using Water (Hydrophobic/Hydrophilic Interactions)

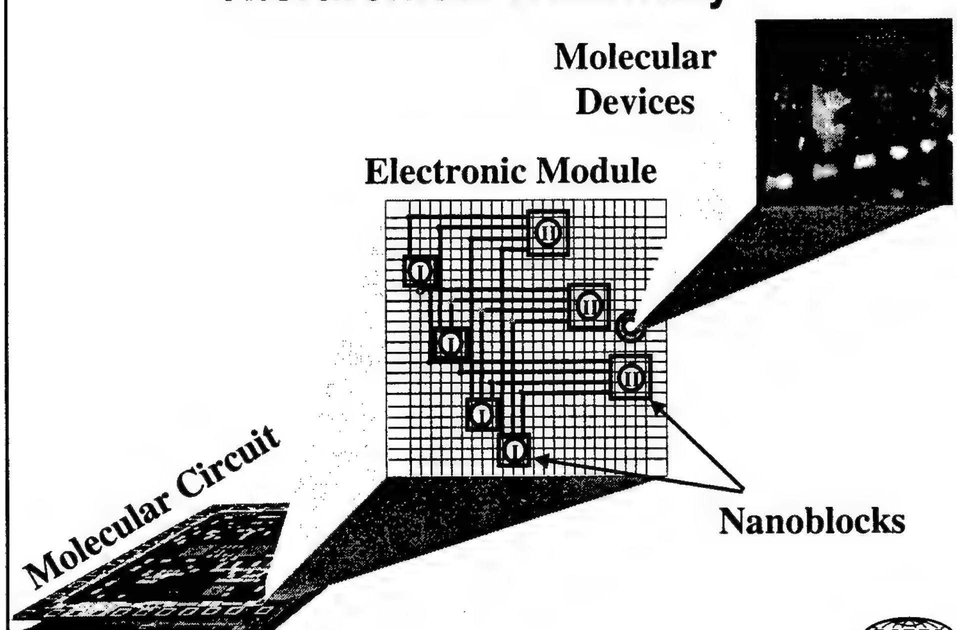


- Chip border used as primary driving force for alignment
- Better than 1 μm alignment achieved across a 2.5 cm substrate
- Local alignment anticipated to be at least 10's of nm



Penn State

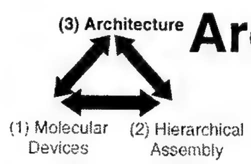
Hierarchical Assembly



Moletronics Objective

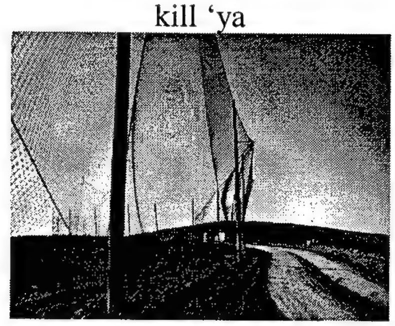
Hierarchical-Assembly Will Reduce The Cost of Electronics Manufacturing

Architecture and Defects



When a single defect could kill 'ya

When defects won't kill 'ya



- Scalable architectures
- Defect tolerance
- Algorithm development

System Architecture Scalability

Power dissipation
Input/Output
Access times …

Supercomputer

10^{12} devices in 1 cm^2

10^{12} Hertz switching speed

~ 10^4 Watts!

Nanocomputer* ~ Pentium III

10^9 devices in 10^{-3} cm^2!

10^9 Hertz

~ 10^{-2} Watts

*Assumes $10^{12}/cm^2$ device density & 2.5 kT/operation

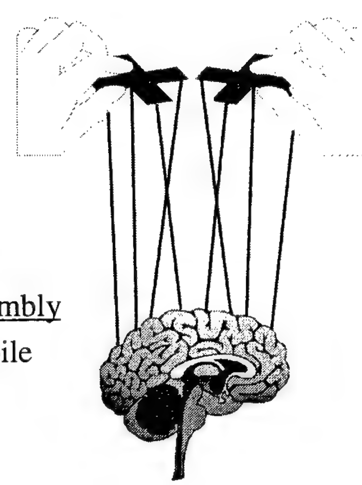
A Molecular Computer that Needs to be "Taken to School"

Old Way: Precision Design and Build

Design - Build - Compile

New Way: Directed Design and Self-Assembly

Build - Measure - Reconfigure - Compile



Comparisons Between Si CMOS and Moletronics

Properties	Si CMOS	Moletronics
Fabrication	Lithography	Hierarchical assembly
Defined properties?	Yes	No
Defects?	No	Yes
Power	Central	Distributed
Approach	Top-down	Bottom-up Top-down

Conclusions

New Materials ↕ New Phenomena

(bottom up)

New Architecture ↕ New Algorithms

(top down)

Molecular/nano materials
Self-assembly
Hierarchical assembly
.
.
.

Multi-state systems
Defect/fault tolerance
Algorithm development
.
.
.

DARPATech 2000

List of Acronyms

A

A.cm-2	Mass. Centimeter squared
A/D	Analog/Digital
AAAV	Advanced Amphibious Assault Vehicle
AAVs	Autonomous Air Vehicles
ABC	Agent Based Computing
Abs	Absolute
ABS	Agent Based System
ACERT	Army Computer Emergency Response Team
ACL	Agent Communication Language
ACN	Airborne Communications Node
ACS	Adaptive Computing Systems
ACTDs	Advanced Concept Technology Demonstrations
ADP	Adenosine Di-Phosphate
ADXL	Analog Devices Accelerometer Series
AEL	Array Element Localization
AESA	Active Electronic Scanned Antenna
AF	Air Force
AF SAB	Air Force Science Advisory Board
AFB	Air Force Base
AFIWC	Air Force Information Warfare Center
AFRL	Air Force Research Laboratory
AFSS	Advanced Fire Support System
AI	Artificial Intelligence

AIA	Autonomic Information Assurance
AIM/DDB	Automated ISR Management/Dynamic Dababase
AIN	Aluminum Nitride
ALP	Advanced Logisitics Program
AME	Advanced Microelectronics
AMFP	Adaptive Match Field Processor
AMP	Adenosine Tri-Phosphate
AMSTE	Affordable Moving Surface Target Engagement
AMTEC	Alkali Metal Thermal to Electric Converter
ANETS	Active Networks
ANR	Active Network Response
ANTS	Autonomous Negotiation Targets
AOA	Angle of Arrival
APCs	Armored Personnel Carriers
APIs	Application Programming Interfaces
APL	Airborne Pseudolite
APLA	Anti-Personnel Landmines
APPL	Application-specific Systems
ARL	Airborne Reconnaissance Low; Army Research Laboratory
ARPANET	ARPA Network
ARPI	ARPA (Advanced Research Project Agency) Rome Laboratory Planning Initiative
ASC/ENM	Aeronautical Systems Center
ASIC	All Source Intelligence Center
ASIC/CPU	Application Specific Integrated Circuit/Central Processing Unit
ASICs	Application Specific Integrated Circuits
ASTRO	Autonomous Space Transfer and Robotic Orbital
ASW	Anti-Submarine Warfare
AT3	Advanced Tactical Targeting Technology

ATD	Advanced Technology Demonstration
ATD/C	Automatic Target Detection/Cueing
ATDNet/MONET	Advanced Technology Demonstration Network
ATM	Asynchronous Transfer Mode
ATO	Advanced Technology Office
A-to-D	Analog to Dialog
ATP	Adenosine Mono-Phosphate; Advanced Technology Program
ATR	Automatic Target Recognition
Au	Gold
AWACS	Airborne Warning and Control System
AX	Acoustic Explorer

B

b	bytes
B	Billion
B/W	Biological Warfare
BAAs	Broad Area Announcements
BADD	Battlefield Awareness and Data Dissemination
BART	Bay Area Rapid Transit
BAW	Bulk Acoustic Wave
BCAA	Buoyant Cable Antenna Array
BDA	Battle Damage Assessment
BiCMOS	Bi-polar Complimentary Metal Oxide Semiconductor
BiFET	Bi-polar Field Effect Semiconductor
Bio	Biology
BIO:INFO:MICRO	Biology:Information:Microbiology
BioFlips	Bio-Fluidic Chips
BIT	Broadband Information Technology

BLM	Bilayer Lipid Membrane
BLOS	Beyond Line Of Sight
BM/C2	Battle Management/Command and Control
BM/C3	Battle Management/Command, Control and Communications
BMDO	Ballistic Missile Defense Office
BMG	Bulk Metallic Glass
BN HQ	Battalion Headquarters
BNS	Battalions
BOX	Barrier Oxide
BW	Biological Weapon; Biological Warfare; Bandwidth
BW/ch	Bandwidth per channel

C

C	Celcius
C/A	Course Acquisition
C2	Command and Control
C3	Command, Control, and Communications
C3I	Command, Control and Communications Intelligence
C4I	Command, Control, Communications, Computers and Intelligence
C4ISR	Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance
CAD	Computer Aided Design
CAPT	Captain
CASE	Computer-Aided Software Engineering
CAST	Cooperative Agents for Specific Tasks

CB	Chemical Biological
CBD	Chemical Biological Defense
CBW	Chemical Biological Warfare
CC&D	Camouflage, Concealment & Deception
CC21	Commander in Chief 21 ACTD
CCI	Co-channel Interference
CCIT	Coherent Communications, Imaging, and Targeting
CDC	Center for Disease Control
CDMA	Code Division Multiple Access
CDR	Critical Design Review; Commander
CdSe	Cadmium Selenide
CEC	Cooperative Engagement Capability
CENTCOM	Central Command
CEP	Critical Error Probability
CERT	Computer Emergency Response Team
CFD	Computational Fluid Dynamics
CHATS	Composable High Assurance Trusted Systems
Chem/Bio	Chemical/Biological
CIB	Common Imagery Base
CID	Criminal Investigation Division, Combat Intelligence Division
CINC	Commander in Chief
CIS	Coalition Infrastructure Services
CLB	Configurable Logic Block
cm	centimeter
cm/s	centimeter/second
cm2	centimeter (squared)
CMD	Command
cm-k	centimeter-kelvin
CMOS	Complimentary Metal Oxide Semiconductor
CMU	Carnegie Mellon University

CNR	Combat Net Radios
CO	Carbon monoxide; Company
CoABS	Control of Agent Based Systems
COM	Component Object Model
COMINT	Communications Intelligence
Comms	Communications
CONOPS	Concept of Operations
CONUS	Continental United States
CORBA	Common Object Request Broker Architecture
COTS	Commercial-Off-The-Shelf
COTS	Commercial Off The Shelf
COUGAAR	Cognitive Agency Architecture
CP	Command Post
CPA	Closest Point of Approach
CpG DNA	Cytosine-phoshate-Guanine(base pair motif) Deoxyribonucleic Acid
CPoF	Command Post of the Future
Cpt.	Captain
CPU	Computer Processing Unit
CRAF	Civil Reserve Air Fleet
CRW	Canard Rotor Wing
CS	Computer Science
cu	cubic
CVBG	Carrier Battle Group
CW	Continuous Wave
CWRU	Case Western Reserve University

D

D+D	Denial and Deception
DAIS	Domain-adaptive Information System
DAML	DARPA Agent Markup Language
DARPA	Defense Advanced Research Project Agency
DASADA	Dynamic Assembly for System Adaptability, Dependability and Assurance
dB	decibel
dBm	Decibel-power of 1 mW
DC	Dynamic Coalitions; Direct Current
DCEs	Distributed Computing Environment
DDOS	Denying Denial-of-Service
deg	degree
DEMs	Digital Elevation Models
DEP/FFF	Dielectrophoresis/Field-Flow Fractionation
DFAD	Digital Feature Analysis Data
DIA	Defense Intelligence Agency
DIS	Data Intensive Systems
DISA	Defense Information Services Agency
DISA GCC	Defense Information Services Agency Global Command and Control
DISCEX	DARPA Information Survivability Conference and Exposition
DMA	Direct Memory Access
DNA	Deoxyribonucleic Acid
DNS	Direct Numerical Simulation
DNS	Defense Network Service
DNSSSec	Domain Name Service Security
DoD	Department of Defense

DOF	Degree Of Freedom
DOS	Denial-of-Service
Dr.	Doctor
DRaFT	Digital Radio Frequency Tags
DRAM	Dynamic Random Access Memory
DSB	Defense Science Board
DSEAD	Distributed Suppression Of Enemy Air Defense
DSL-s	Digital Subscriber Line
DSO	Defense Sciences Office
DSP	Digital Signal Processor
DTED	Digital Terrain Elevation Data

E

EAC	Echelon Above Corp
EB - DVD	Electron Beam - Directed Vapor Deposition
ECCM	Electronic Counter-Counter Measures
ECM	Electronic Counter Measures
EDA	Electronic Design Automation
EDCS	Evolutionary Design of Complex Systems
EDFA	Erbium Doped Fiber Amplifier
EE	Electrical or Electronic Engineering
EEIs	Essential Elements of Information
EELD	Evidence Extraction and Link Discovery
Eg	Energy gap
EHF	Extremely High Frequency
ELINT	Electronic Intelligence
EM	Electromagnetic
EMD	Engineering Management Decision

EMI/EMC	Electro Magnetic Interference/Electro Magnetic Control
ENCOMPASS	Enhanced Consequence Management Planning and Support System
EO	Electro-Optical
EO/IR	Electro-Optical/Infrared
EP	Electronic Protection
EPLRS	Enhanced Positioning, Locating, Ranging System
Er	Erbium
ERGM	Extended Range Guided Munition
ErSi2	Erbium Silicide
ESA	Electronically Scanned Array
ESM	Electronic Support Measures
ESRT	Electron-Spin Resonance Transistor
eV	electron Volt
EW	Electronic Warfare

F

F&S	Force and System
FAME	Frequency Agile Materials
FBE	Fleet Battle Experiment
FCS	Future Combat Systems
FDOA	Frequency Difference of Arrival
FEM	Finite Element Model
FEMA	Federal Emergency Management Agency
FETs	Field Effect Transistors
FF	Fast Frigate
FFP	Full Field Processing
FFT	Fast Fourier Transform
FIDNET	Federal Intrusion Detection Network

FIPA	Foundation for Intelligent Physical Agents
FIWC	Fleet Information Warfare Center
FlexML	Flexible Markup Language; Flexible Motor Language
FLIR	Forward Looking Infrared
FLT	Flight
FoF1	path for a specific type of biomolecular motor
FOPC	First-order Predicate Calculus
FOPEN	Foliage Peneration
FPA	Field Programmable Array
FPGAs	Field Programmable Gate Arrays
FRR	Final Readiness Review
FSCS	Future Scout Cavalry System
FSMs	Functional Size Measurement
FTN	Fault Tolerant Network
FTS	Fault-Tolerant Survivability
FUE	Full Up Element
FY	Fiscal Year

G

g	gram
GaAs	Gallium Arsenide
GaAs/ZnSe	Gallium Arsenide/Zinc Selenide
GaMnAs	Gallium Manganese Arsenide
GaN	Gallium Nitride
GAO	General Accounting Office
Gb	Gigabytes
Gb/s	Gigabytes/per second
GBPS	Giga Bits Per Second
GCDS	Ground Control and Display System

GCN	Ground Control Network; Government Computer News
GDP	Gross Domestic Product
GFE	Government Furnished Equipment
GGP	GPS Guidance Package
GHz	Gigahertz
gm	grams
GMR	Giant Magneto-Resistance
GMTI	Ground Moving Target Indicator
Gohm	Gigaohm
GOPS	Billion Operations Per Second
GOPS/W	Billion Operations Per Second Per Watt
GOTS	Government Off the Shelf
Govt.	Government
GP	General Processor
GPL	Ground Pseudolight
GPS	Global Positioning System
GPS INS	Global Positioning System Inertial Navigation System
GPX	Global Positioning Experiment

H

h	heat transfer coefficient; Planck's constant
H2	Hydrogen gas
HBT	Heterojunction Bi-polar Transistor
HCLOS	High Capacity Line-Of-Sight
HDS	High Defintion Systems
HDTV	High Definition Television
HERETIC	Heat Removal Thermal Integrated Circuits
HF	High Frequency

HFET	Heterojunction Field Effort Transistor
HID	Human ID at a Distance
HIMARS	High Mobility Artillery Rocket System
HLA	Horizontal Line Array
HMD	Helmet Mounted Display
HMMWV	High Mobility, Multi Wheeled Vehicle
HNS	Host-Nation Support
HOLs	High Order Logic
HP	Hewlett Packard
HPKB	High Performance Knowledge Base
HQS	Headquarters
hr	hour
HRR	High Range Resolution
HSCC	High Speed Connectivity Consortion
HSI	Hyperspectral Imager
HSI/MSI	Hyper-Spectral Imagery/Multi-Spectral Imagery
HTLE	Horizontal Target Location Error
HTML/XML	Hypertext Markup Language/Extensible Markup Language
HTTP	Hypertext Transfer Protocol
HumanID	Human Identification at a Distance
HUMINT	Human Intelligence
HV	High Vacuum
HW	Hardware
Hz	Hertz

I

I&W	Indications and Warning
I/O	Input/Output
I3	Intelligent Integration of Information

IA	Input Axis
IA	Information Assurance
IA&S	Information Assurance & Survivability
IADS	Integrated Air Defense System
IC	Integrated Circuits
ICBMs	Inter Continential Ballistic Missiles
ICL	Interactive Command Language
ID	Identification; Intrusion Detection
IDS	Intrusion Detection Systems
IEDM	International Electronics Device Meeting
IETF MANET	Internet Engineering Task Force Mobile Ad-hoc Network
IF	Intermediate Frequency
IFM	Interconnect Fabric Element
III-N	Type 3 material with Nitrogen
IMINT	Imagery Intelligence
IMO	Intelink Management Office
IMU	Inertial Measurement Unit
in	inches
InAs/GaSb/AlSb	Indium Arsenide/Gallium Antimonide/Aluminum Antimonide
Info	Information
InP	Indium Phosphide
INSCOM	Intelligence and Security Command (US Army)
In-situ	In Place
INT	Intelligence
Inter-MCM	Interconnect connection for Multi-Chip Module
IOC	Initial Operating Capability
IOR	Interim Open Review
IP	Internet Protocol
IPB	Intelligence Preparation of the Battlefield
IPSEC	Internet Protocol Security

IR	Infrared
IS	Information System
ISAT	Incremental Satisfiability
ISCR	Interim System Concept Review
ISI-East	Information Sciences Institute-East
ISO	Informations Systems Office
Isp	Specific Impulse
ISP	Internet Service Provider
ISR	Independent Search and Rescue; Intelligence, Surveillance and Reconnaissance
ISRR	Interim System Risk Review
IT	Information Technology
ITO	Information Technology Office
IW	Information Warfare

J

J/S	Jammer to Signal Ratio
JARS	Java Applet Rating Service
JBI	Joint Battlespace Infosphere
JCSE	Joint Communication Support Element
JDAM	Joint Direct Attack Munition
JFACC	Joint Force Air Component Commander
JIATF-E	Joint Inter-agency Task Force - East
JIP	Just In-time Power
Joint STARS	Joint Surveillance Target Attack Radar System
JPL	Jet Propulsion Laboratory
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Target Attack Radar System

JTF	Joint Task Force
JTIDS	Joint Tactical Information Distribution System
JV	Joint Vision

K

K	kilowatts, thousand
KB	Kilobytes; Knowledge Based
Kcal/mol	kilocalorie per mole
KE	Kinetic Energy
Kg	Kilogram
KHz	Kilohertz
KLA	Kosovo Libertation Army
Km	Kilometers
kohm	kilo-ohm
KQML	Knowledge Query and Manipulation Language
kW	kilowatts
kW-hr	kilowatts – hour

L

LADAR	Laser Radar
LAN	Local Area Network
LAVs	Light Armored Vehicles
lbs	pounds
LEDs	Light Emitting Diodes
LEO	Low Earth Orbit
LES	Large Eddy Simulation

Lg	gate Length
LIGA	Lithography
LIWA	Land Information Warfare Activity
LLNL	Lawrence Livermore National Laboratory
Lm	L-band (military code)
LMDS	Local Multiport Distribution Service
LO	Low Observable
LOS	Line Of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LTC	Lieutenant Colonel
LtCol	Lieutenant Colonel

M

m	meter
M&S	Modeling and Simulation
mA	milliamps
MAFC	Micro Adaptive Flow Control
MAFET	Microwave and Analog Front End Technology
MAR CAX	Marine Combat Arms Exercise
MARS	Mobile Autonomous Robot Software
MAV	Micro Air Vehicle
Mb	Megabytes
Mbps	Megabits per second
mC	Microcontroller
MC	Malicious Code
MCAGCC	Marine Corps Air Ground Combat Center
MCE	Mission Control Element
MCMs	Multi Chip Modules

MCS	Mission Control Station
MDCP	Multi-Dimensional Coalition Policies
MECH	Mechanized
MEMS	Micro Electro Mechanical System
MEMS INS	Micro Electro Mechanical System Inertial Navigation System
MEMS-RF	Micro Electro Mechanical System - Radio Frequency
MFP	Matched Field Processor
MHT	Multiple Hypothesis Tracker
MHz	Megahertz
Micro	Microsystems
MicroFlumes	Microfluidic Molecular Systems
micro-g	micro-gravity
Microsat	Microsatellite
MIMIC	Microwave Monolithic Integrated Circuits
MIPS	Model Integrated Program Synthesis
MIT	Massachusetts Institute of Technology
MIT/LL	Massachusetts Institute of Technology/Lincoln Laboratory
mK	milliKelvm
MLP	Molecular-Level Large-Area Printing
MLRS	Multiple Launch Rocket System
mm	millimeter
MMIC	Miniature Millimeter Wave Integrated Circuit
MMW	Millimeter Microwave
MOA	Memorandum Of Agreement
MoBIES	Model-Based Integration of Embedded Systems
Moletronics	Molecular Electronics
MOS	Metal Oxide Semiconductor
MOSFET	Metal Oxide Semiconductor Field Effort Transistor

MOUT	Military Operations in Urban Terrain
MOVINT	Movement Intelligence
MPG	Micro Power Generation
MRC	Major Regional Contingency
MRVs	Multiple Re-entry Vehicles
MS	Message Switch
ms	milliseconds
MSCR	Mission System Capability Review
msec	millisecond
MSIP	Multinational Staged Improvement Program
MSRR	Modeling and Simulation Resource Repository
MSTAR	Moving and Stationary Target Acquisition and Recognition
MTE	Moving Target Exploitation
MTI	Moving Target Indicator
MTO	Microsystems Technology Office
MTW	Major Theater of War
mV	millivolt
MV	Mega Volt
MVBM	Micro Vibrating Beam Multisensor
MVDR	Minimum Variance Distortionless Receiver
Mw	milliwatt

N

N	Negative charge
NA	Not Applicable
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration

NATO	North Atlantic Treaty Organization
NAV	Navy
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NAWC-CL	Naval Air Warfare Center - China Lake
NCA	National Command Authority
NDR	Negative Differential Resistance
NFOV	Narrow Field of View
NGI	Next Generation Internet
Ni-NTA	Nickel NTA
NIPC	National Infrastructure Protection Center
NLOS	Non Line Of Sight
nm	nanometer; nautical miles
NMS	Network Modeling and Simulation
NodeOS	Node Operating Systems
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
ns	nanoseconds
NSA	National Security Agency
NSB	National Science Board
nsec	nanosecond
NSWC	Naval Surface Weapons Center
NTC	National Training Center
NTM	Notice to Mariners
NTON II	National Transparent Optical Network
nW	nanowatt

O

O&S	Operations and Support
O(n2)	Order N^2

O/E	Opto-Electronic
OAA	Open Agent Architecture
OCP	Open Control Platform
OMNET	Optical Micro-networks
ONR	Office of Naval Research
ONRAMP	Optical Network for Regional Access over Multi wavelength protocol
OODA	Observe, Orient, Decide, Act
OOTW	Operations Other Than War
Ops	Operations
OPTEMPO	Operational Tempo
Opto	Optical
OR	OR Logic Gate
ORBREP	Orbital Replenishment
ORUs	Orbital Replacement Units
OS	Operating Systems
OSAM	Office of Spectrum Analysis & Management
OSC	Operational System Concept
OWL	Ontology Web Language

P

p	Positive charge
P[CA]	Probability of Correct Association
P3I	Preplanned Product Improvement
pA	pico-Ampheres
Pa	Pascal
PAC/C	Power Aware Computing/Communication
PACOM	Pacific Command
PACT	Photonic A/D Converter Technology
PAE	Power Added Efficiency

Pamp	Power amplified
PASEM	Passive Acoustic, Seismic & EM
PC	Personal Computer
PCA	Polymorphous Computing Architectures
PCB	Printed Circuit Board
PCES	Program Composition for Embedded Systems
PCI	Peripheral Component Interface
PCR	Polynerase Chain Reaction
PdH	Palladium Hybride
PDR	Preliminary Design Review
PEM	Proton Exchange Membrane
PFCT	Precision Fire Control Tracking
PG	Proving Ground
PGA	Pin Grid Array
PGP	Pretty Good Privacy
pH	Chemical standard indicating acidity of a solution alloy
PHEMTs	Pseudomorphic High Electron Mobility Transistors
Pi	Inorganic Phosphate
PI	Principle Investigator
PIM	Point or Path of Intended Movement
PKI	Public-Key Infrastructure
PLGR	Precision Lightweight GPS Receiver
PM	Program Manager
pN-nm	pico-Newtons-nanometer
POF	Plastic Optical Fiber
POM	Program Objective Memorandum
POWs	Prisoners Of War
P-Ps	Peer-to-Peers
PRI	Pulse Repetition Interval
psec	picosecond

PVR	Peak to Valley Ratio
pW	picowatt
P-WASSP	Photonic Wavelength & Spatial Signal Processing
PZT	Lead Zirconium-Titanium alloy

Q

QoS	Quality of Service

R

R	Resistance
R&D	Research & Development
RAM	Random Access Memory
RANS	Reynolds Average Navier Stokes
RDF	Resource Description Framework
RECAP	Reconfigurable Aperture
REMBASS	Remotely Monitored Battlefield Sensor System
RF	Radio Frequency
RFI	Radio Frequency Interference
R-FLICS	Radio Frequency Lightwave Integrated Circuits
RFP	Request For Proposal
RIE	Regative Ion Etching
RISC	Reduced Instruction Set Computer
RISC/DSP	Reduced Instruction SLT Computer/Digital Signal Processor
RKF	Rapid Knowledge Formation
RMI	Remote Method Invocation

RNA	Ribonucleic Acid
ROI	Region of Interest
ROM	Read Only Memory
RPS	Robust Passive Sonar
rps	rotations per second
RR&OE	Risk Reduction and Operational Evaluation
RST	Reconnaissance, Surveillance and Targeting
RSTV	Reconnaissance, Surveillance and Targeting Vehicle
RTOS	Run-Time Operating System
Rx	Receive; Prescription

S

S&T	Science & Technology
S/N	Signal to Noise Ratio
SAM	Structural Amorphous Materials; Self-Assembled Monolayer; Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SAR/MTI	Synthetic Aperture Radar/Moving Target Indicator
SAS-SUO	Situation Awareness System-Small Unit Operation
SAT	Boolean Satisfiability Problem
SATCOM	Satellite Communications
SAW	Surface Acoustic Wave
SBCX	Santa Barbara Channel Experiment
SBIRS	Small Business Innovation Research Projects or Space Based Infrared Systems
SCD	Source Control Drawing

SDIO	Strategic Defense Initiative Office
SDR	Software for Distributed Robotics
SDRAM	Synchronous Dynamic Random Access Memory
SEAD	Suppression of Enemy Air Defense
SEC	Software Enabled Control
secs	seconds
SensIT	Sensor Information Technology
SEP	Spherical Error Probable
SETA	Scientific, Engineering and Technical Assistance
SGM	Secure Group Management
SHF	Super High Frequency
SHIPN	Secure High-speed IP Networking
SHOE	Simple HTML (Hypertext Markup Language) Ontology Extension
Si	Silicon
Si CMOS	Silicon Complementary Metal Oxide Semiconductor
Si fab	Silicon Fabrication
SIA	Semiconductor Industry Association
SiC	Silicon Carbide
SiGe	Silicon Germanium
SIGINT	Signals Intelligence
SINCGARS	Single Channel Ground and Air Radio Systems
SINR	Signal to Interference Ratio
SiO2	Silicon Dioxide
SMA	System Maturation Assessment
SMEs	Subject Matter Experts
SMF	Single-Mode Filter
SMP	System Maturation Plan
SOA	Semiconductor Optical Amplifier
SOFC	Solid Oxide Fuel Cell

SOG	Sensor Oversight Group
SOI	Signals of Interest; Silicon On Insulator
SONET	Synchronous Networking
SPINS	Spins IN Semiconductors
Spintronics	Spin Electronics
SPO	Special Projects Office
sq.km.	square kilometer
SQL	Structured Query Language
SRA	Specialized Repair Activity
SSA	Solid State Amplifier
STAB	Steered Agile Beams
STAP	Space-Time Adaptive Processing
START	SynTactic Analysis using Reversible Transformations
SUMOWIN	Survivable Mobile Wireless Networking
SUO	Small Unit Operations
SVC PLT	Services Platoon
SVR	Surface-to-Volume Ratio
SW	Software
SWaP	Size, Weight and Power
SWEPT	Size, Weight, Energy, Performance, Time
SWP	Size, Weight, Power

T

T&E	Test & Evaluation
T&V	Test and Verification
T/R	Transmit/Receive
TASK	Taskable Agent Software Kit
TASS	Terminal Analog Speech Synthesizer
TBD	To Be Determined

TBMD	Theater Ballistic Missile Defense
Tbytes	Terabytes
TCT	Time Critical Targets
TDOA	Time Difference Of Arrival
TE	Thermo Electric
TELs	Transporter Erector
TERCOM	Terrain Contour Matching
TF/TA	Terrain Following/Terrain Avoidance
TFG	Tuning Fork Gyro
TFR	Terrain Following Radar
TIDES	Trans-Lingual Information Detection
TIEs	Technology Integration Experiments
TIGER	Targeting by Image Geo Registration
TIM	Technical Interchange Meeting
TIS	Trusted Information Systems
TLE	Two Line Element
TMR	Tactical Mobile Robots
TNT	Tri-Nitro Toluene
TOC	Total Ownership Costs
Tox	Oxide Thickness
TPED	Tasking Processing Exploitation and Dissemination
TPSAs	Technologies Processes and System Attributes
TPV	Thermal Photo Voltaic
TRADOC	U.S. Army Training and Doctrine Command
TRL	Technology Readiness Level
TRSS	Tactical Remote Sensory System
TSM	Trunk Signaling Message
TST	Technical Support Team
TTO	Tactical Technology Office
TUAVs	Tactical Unmanned Air Vehicles

TV	Television
Tx	Transmit

U

UAVBL	Unmanned Air Vehicle Battle Laboratory
UAVs	Unmanned Air Vehicles
UC	University of California
UCAV	Unmanned Combat Air Vehicle
UCAV-N	Unmanned Combat Air Vehicle - Naval
UCB	University of California Berkeley
UCLA	University of California-Los Angeles
UCLA/HP	University of California Los Angeles/Hewlett-Packard
UDS-N	UCAV Demonstrator System - Naval
UE	User Equipment
UGF	Underground Facilities
UGS	Unattended Ground Sensors
UHF	Ultra High Frequency
UIUC	University of Illinois Urbanna-Chapaign
UK DERA	United Kingdom Defense Evaluation and Research Agency
UL	Ultra Log
UNREP	Underway Replenishment
UOS-N	UCAV Operational System - Naval
UPa/Hz	Micro Pascals per Hertz
UPC	Unconventional Pathogen Countermeasures
US	United States
USA	United States Army
USAF	United States Air Force
USC	University of Southern California

USC/HRL	University of Southern California/HRL
USMC	United States Marine Corps
USN	United States Navy
USN-R	United States Navy - Reserve
USS	United States Ship
UV	Ultra Violet
uW	Microwave

V

V	Voltage
V/STOL	Vertical/Standing Take Off Landing
VCSELs	Vertical Cavity Surface-Emitting Lasers
Vd	drain Voltage
VHDL	VHSIC Hardware Description Language
VHF	Very High Frequency
VHF/UHF	Very High Frequency/Ultra High Frequency
VHSIC	Very High Speed Integrated Circuit
VLA	Vertical Line Arrays
VLSI	Very Large Scale Integration
Vol.	Volume
Vp	V-pi
VPNs	Virtual Private Networks
Vs	Saturation Velocity
VTOL	Vertical Take Off and Landing

W-Z

W	Watts
W/kg	Watt/kilogram
W3C	World Wide Web Consortium
WAE	Wargaming the Asymmetric Environment
WANs	Wide Area Networks
WASSP	Wavelength & Spatial Signal Processing
WBC	White Blood Cells
WBG	Wide Bandgap
WDM	Wavelength Division Multiplexing
WDM/TDM	Wavelength Division Multiplexing/Time Division Multiplexing
Whr/kg	Watt hour/kilogram
WIN-T	Warfighter Internet-Terrestrial
WMD	Weapons of Mass Destruction
WSTS	Weapons Systems Trade Studies
XML	Extensible Markup Language

DARPATECH
2000 SYMPOSIUM

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